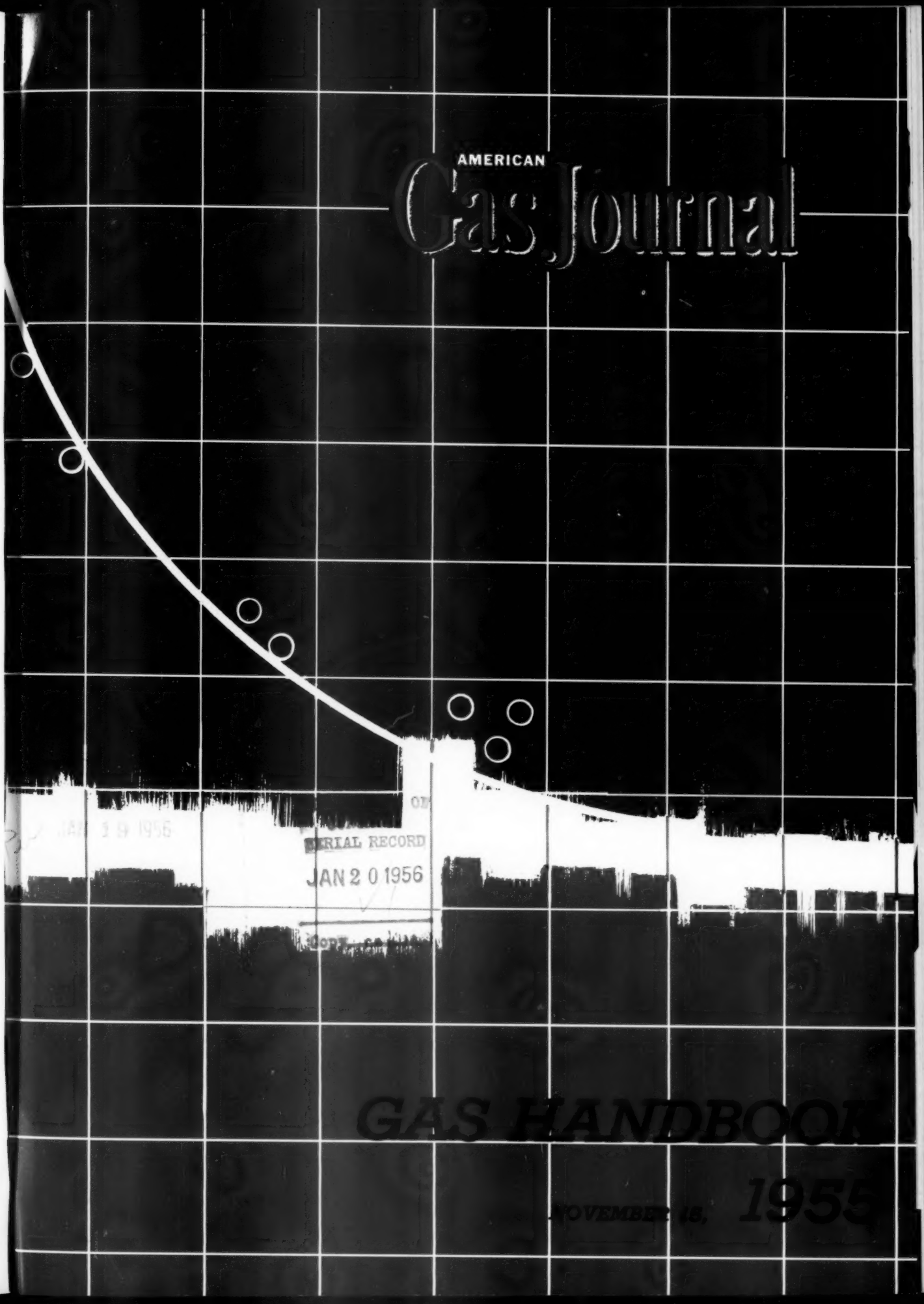

AMERICAN

Gas Journal

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GAS HANDBOOK

NOVEMBER 16, 1955

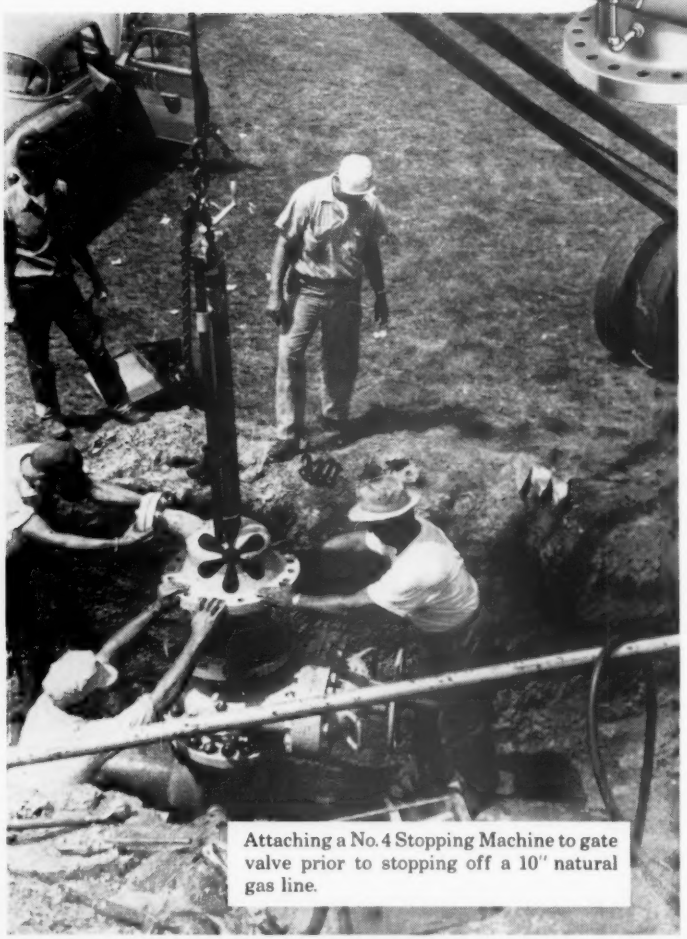
MUELLER

No.4

LINE STOPPER UNIT

NO-BLO

* H-17440 LINE STOPPER UNIT
For 10" and 12" Steel Pipe
Max. Working Pressure – 500 p.s.i. at 100° F
Max. Working Temperature – 250° F at 375 p.s.i.



Attaching a No. 4 Stopping Machine to gate valve prior to stopping off a 10" natural gas line.

RELOCATE OR REPAIR 10" AND 12" LINES SAFELY WITHOUT INTERRUPTING SERVICE

The Mueller No.4 Line Stopper Unit makes it possible to completely isolate a section of line while continuing service through a temporary by-pass. The isolated section may then be repaired, removed or abandoned and the new line tied in.

All stopping-off operations are accomplished under pressure with no blowing of gas or interruption of service.

Contact your Mueller Representative, consult your G-97 Gas Catalog or write direct for complete information.

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JAN 19 1956

REPAIR BROKEN MAINS IN 15 MINUTES!

One-man job . . . any pressure . . . terrific economy! Not only splices main, but *sealed gasket* absorbs future traffic jar or frost heaving! Refer to page 8 of our new Catalog GW. M. B. Skinner Co., South Bend 21, Indiana.

SIZES 2" TO 24" INCL.

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Complete service including all technical phases from project, survey and design to purchasing, fabrication, and construction.

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(U.S. Patent 2,700,601)
a non-regenerative type of machine especially suited for use with light oil. A simple and inexpensive conversion.

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(U.S. Patent 2,700,602)
Designed and developed by Semet-Solvay, this machine insures satisfactory gas production on a continuous 24 hour basis. Because you get *positive carbon removal during the regular cycle*, you need no stand-by time for scurfing — even with oil as heavy as Bunker "C". High thermal production capacity. Most efficient of the low cost conversions.

Semet-Solvay Regenerative Reverse Flow Process—
(U.S. Patents 2,605,176 and 2,605,177)
Outstanding features are its high capacity with both low carbon and high carbon oils. Requires minimum man power, has fast start-up and ease of control.

3 EQUIPMENT FOR THE GAS INDUSTRY

Ammonia Recovery and Concentration Apparatus—Accumulators (Low Pressure Steam)—Blue Gas Plants—Blast Gates—Bunker "C" Oil Systems—Carbon Monoxide Generating Plants—Condensers (Tubular)—Charging Machines (Fuel)—Cooling Coils—De-Emulsifiers—Fuel Handling Systems—Heat Exchangers—High BTU Oil Gas Machines—Light Oil Recovery Plants—Mechanical Grates—Multiple Washers—Pipe and Fittings (Welded)—Producer Gas Plants—Purifiers and Trays—Reverse Flow Carbureted Water Gas Machines—Scrubbers and Grids—Tar Cameras—Tar Extractors—Washer Coolers——Waste Heat Boilers—Valves (Hydraulic and Hand Operated)—Valves (Reversing Three-Way).

SEMET-SOLVAY ENGINEERING DIVISION

Allied Chemical & Dye Corporation
40 Rector St., New York 6, N. Y.

Allied Chemical

AMERICAN
Gas Journal

VOLUME 182 — 97TH YEAR : : NOVEMBER 15, 1955 — NUMBER 13

New Cover . . .
New Book . . .

The cover is a modernized version of a well known curve — the Terzian Factor. It aptly depicts the new concept of the handbook issue of the American Gas Journal, that is functional engineering data for the industry. This new face heralds a comprehensive handbook compiled exclusively for the gas utility industry. Every effort has been made to provide you with the most up-to-date technical information, streamlined into a handy package for easy reference.

It is not intended that these 125 pages should replace the weighty reference books used by the reader. Data are specialized, pertinent to utilities only, and are designed as a working tool for use in solving your day-to-day problems.

It is strongly recommended that this handbook be kept close at hand. It has been field tested, found to save time whether in gas sales, engineering, manufacturing or operation. Your editors sincerely hope that this handbook will prove invaluable to you — as it has to many others.

James A. LeVelle
Engineering Editor

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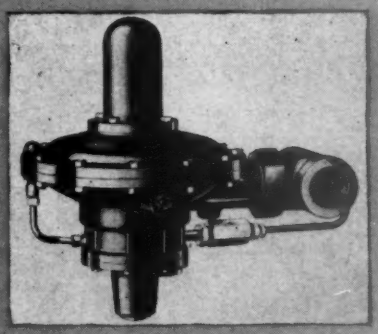

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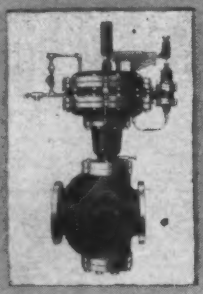
Self-contained pilot-operated gas regulator for small border stations and industrial applications. 2" size only. Reduced pressure range 4 ozs. to 65 lbs.



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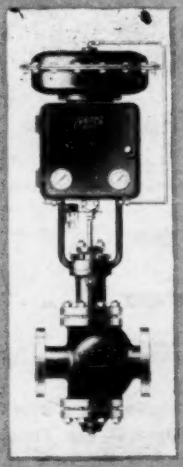
The Fisher King Booster is an entirely self-contained pressure controller. It will maintain a constant pressure at the low pressure point in the distribution system regardless of demand load.



TYPE 4100U-657

High-pressure reducing valve for border stations—high-pressure regulation and industrial applications.

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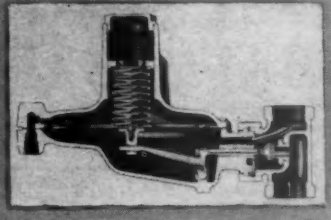
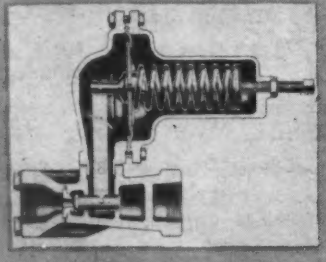
FISHER® America's



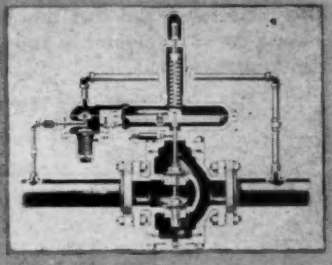
TYPE 730C

Standard gas service regulator with or without integral relief valve, bug-proof vent. Sizes ¾" to 2".



TYPE 630

"Big Joe" pressure regulator for high-pressure field and pipe line installations. Sizes 1" and 2". Reduced pressure range 5 to 200 pounds. Inlet pressure up to 1000 lbs.



TYPE 298

Pilot-operated gas pressure regulator—non-bleed construction—for border station and district regulator applications, for low and intermediate pressures. Sizes 2" and up.

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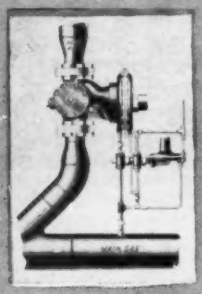
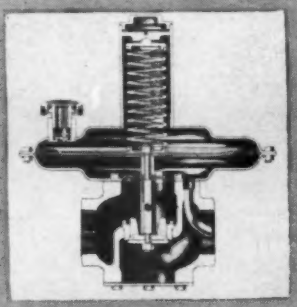
LEADS THE INDUSTRY IN RESEARCH FOR



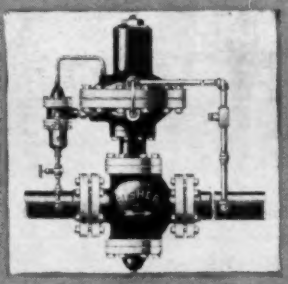
TYPE 29

Full capacity relief valve for distribution systems where large volumes may be discharged without a substantial increase in system pressures. For complete protection against excessive pressures.



TYPE 66

Low-pressure sensitive industrial regulator for inlet pressure up to 5 lbs. Reduced pressure "WC to 1 lb. Sizes 2", 3", and 4".



TYPE 880

High-pressure gas regulator with no bleed to atmosphere, for border stations, loop lines, and big industrials. Extreme stability combined with excellent performance.

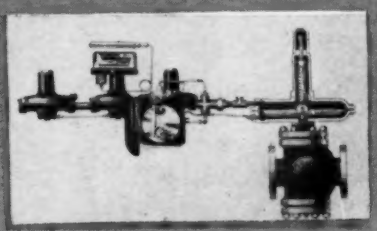
GAS MEN PREFER

Best Gas Regulators

The Industry's Most Complete Line

Fisher Governor Company's wide variety of regulators handle control applications ranging from the natural gas well head to burner utilization. Illustrated are just a few of the varieties of construction.

This complete Fisher line of regulators for the gas industry includes District Regulators, high, low and intermediate pressure — Distribution Regulators — House Service Regulators—High Pressure Field Regulators—Boiler Gas Fuel Governors — Booster Regulators — Safety Shut-Off Regulators—Town Border Station Regulators—Industrial Gas Regulators—Meter Run Regulators.



TYPE 298A-831LTC

As a district regulator the Fisher Time Temperature Booster will automatically increase the low pressure when the temperature drops to compensate for the increased load of residential heating. It automatically lowers the pressure during high-temperature periods.

COMPANY • Marshalltown, Iowa

FISHER

Since 1880

BETTER GAS PRESSURE CONTROL

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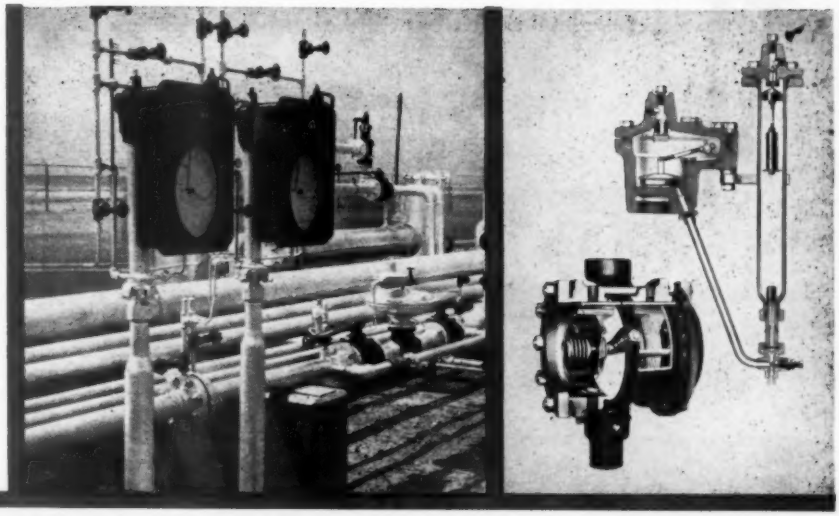
CONTINUOUS RECORDING of flows and pressures in this oil refinery pipe line is accomplished by two American Orifice meters. Meters used in this installation are mercury manometer type.

MERCURY OR DRI-FLO TYPE METERS are available from American to handle a wide range of flow and pressure requirements. Series A-88 American Westcott Mercury Manometer shown is available for working pressures of 1,800, 3,000 and 5,000 psi (1,800 psi unit illustrated at upper right). When mercury manometers are not desired, American Dri-flo orifice meters are available in 20", 50", 100" and 200" ranges, working pressures to 1,000 psi.



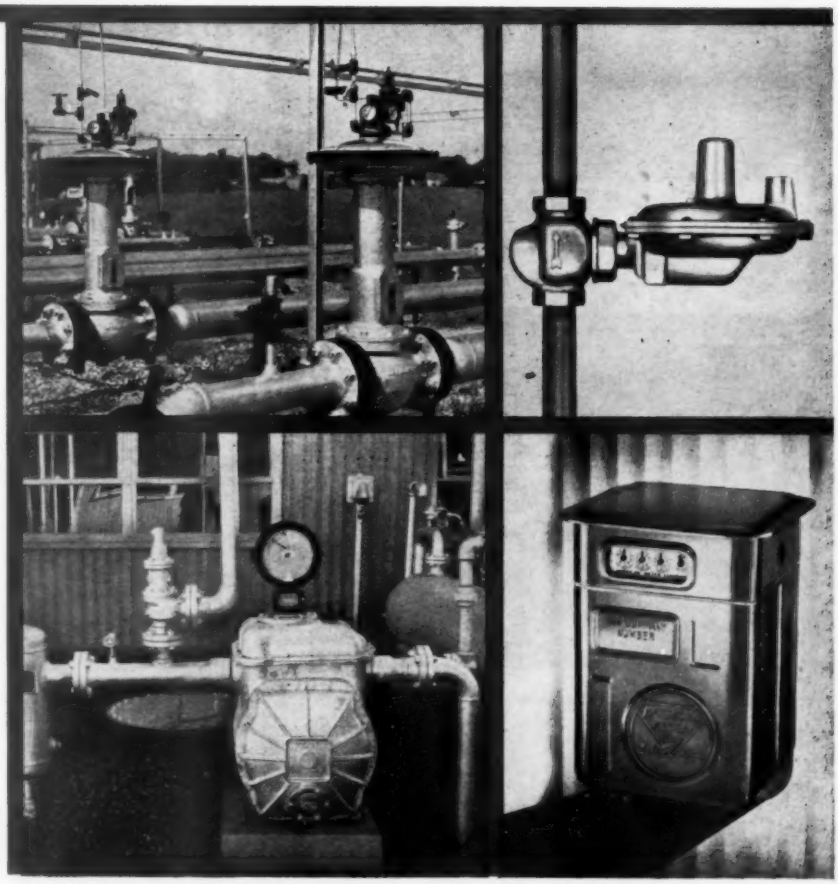
FIRST CHOICE FOR PRECISION in gas measurement and control

RELIANCE REGULATOR, Type CVBA, shown at left, is designed for use as a spring-loaded reducing regulator, motor valve or back pressure regulator. Normally available to handle inlet pressures up to 600 psi; can be furnished in stainless steel for pressures to 1,000 psi.

HOUSEHOLD AND SERVICE INSTALLATIONS requiring regulation of flow at lower pressures to 100 psi are ideally served by Series 1400 Regulator shown at right. Readily adaptable to a wide range of inlet pressures, these regulators have been chosen for their precision by users the world over.

IRONCASE METERS in a full range of sizes and capacities are available from American. Model shown at left is Type 250B — handling up to 53,000 cfh of 0.6 specific gravity gas at 250 lb. gage pressure. Modifications of basic design include special diaphragms for specific gases; available indexes to meet specific customer needs; tapped and plugged to permit attachment of recording Volume and Pressure Gages and other devices.

NEW CONCEPT IN THE ECONOMICS of gas metering for the home is the American W-60 Welded Steelcase Meter shown here — small, sturdy, with ample capacity for small load applications, the W-60 may solve many of your most pressing economic problems. Write for a detailed discussion of its potential contributions to *your* operations.



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MEXICO: Guillermo Murguia, S. A. Abraham Gonzalez, Num. 48, Mexico 6, D. F.

VENEZUELA: Oficina Tecnica Stubbins, C. A. Apartado Number 7, Caracas

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CANVAS-COVERED GAS MAIN BAGS

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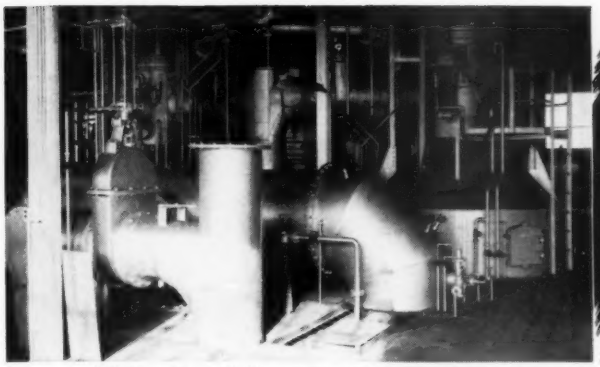

Oil Gas. Two Shell and Four Shell Regenerative Sets. Conversion of Water Gas Sets to Twin Generator or Single Burner Type.

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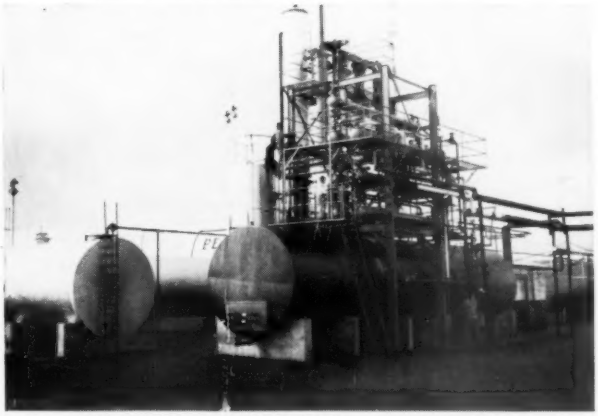

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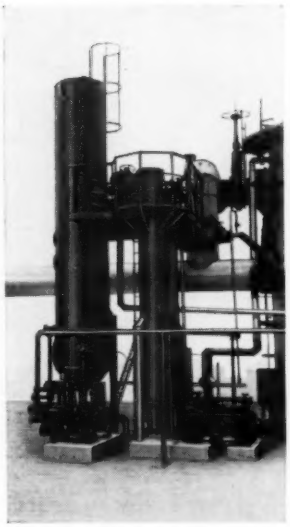
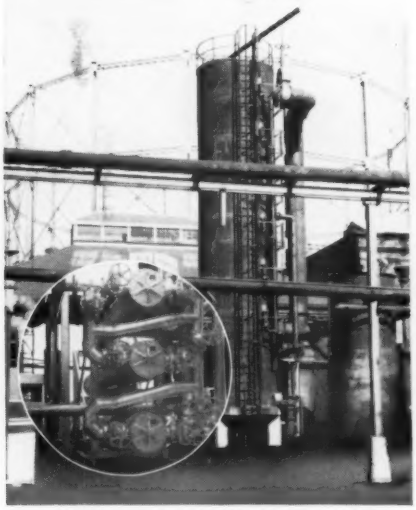
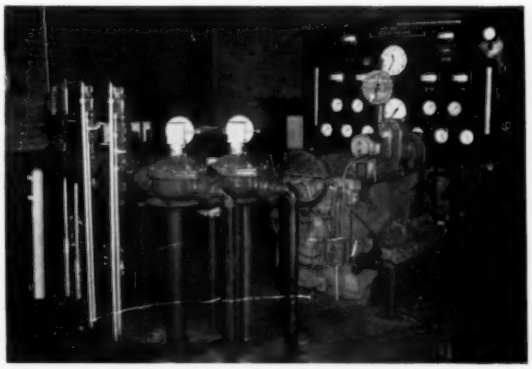
Iron Oxide Purifiers with Valve Manifold and Cover Lifting Crane. Also built in high pressure design.



Tar Dehydration Equipment.



Cooling Scrubbers, Multiple Spray Type, with Gas Liquor Coolers.



Automatic Controls, Gauge Boards, and accessories.

GASMACO has these and many other items for the gas plant, such as equipment and processes for thermal or catalytic cracking of hydrocarbon feeds and for liquefaction, storage and regasification of natural gas.

Call or write for a list of GASMACO's complete line of equipment and services. Our engineers will be pleased to review your requirements and to prepare special designs if needed.

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Gas Plant Equipment and
Industrial Furnaces

THE GAS MACHINERY CO. (Canada), Ltd.
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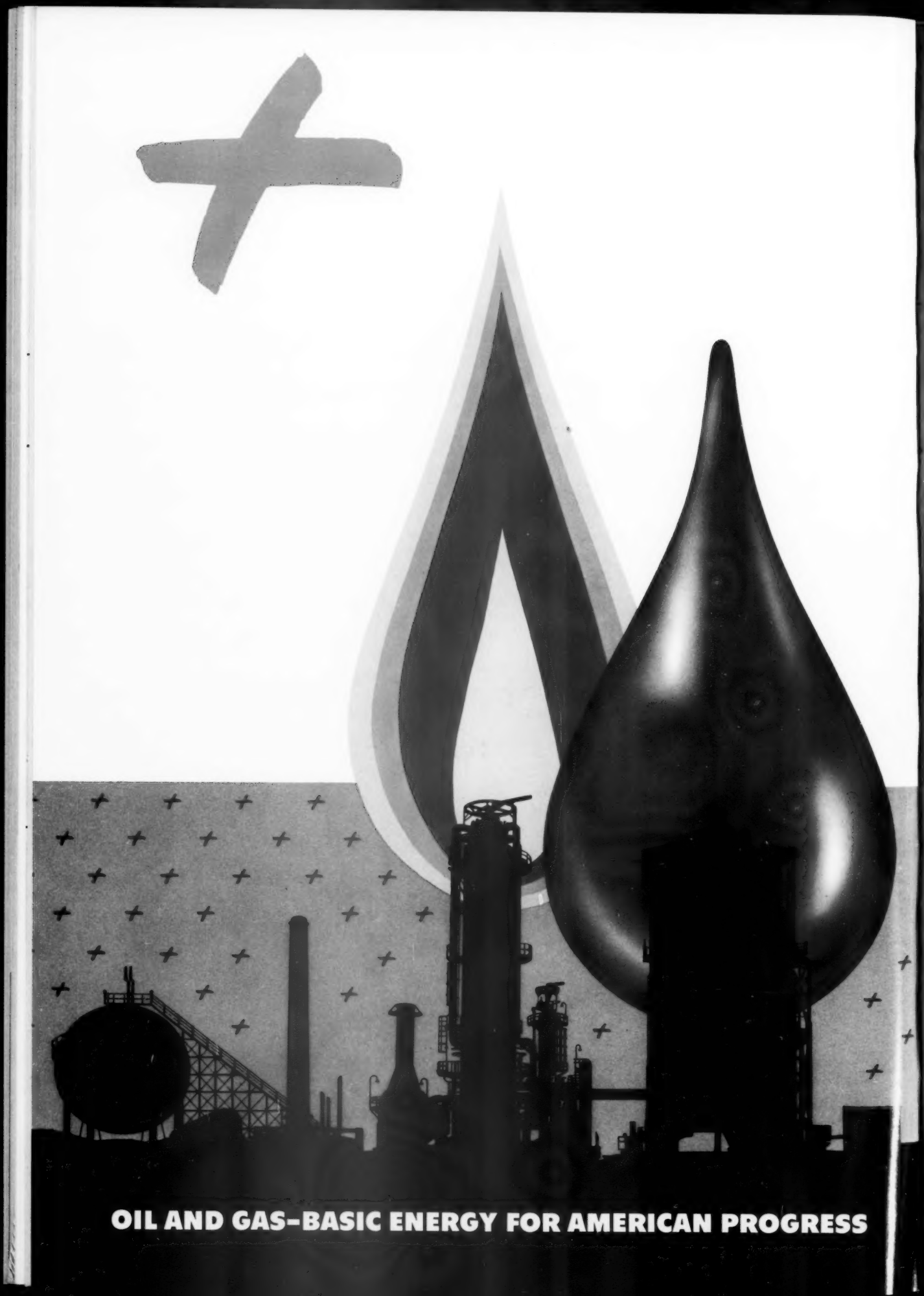
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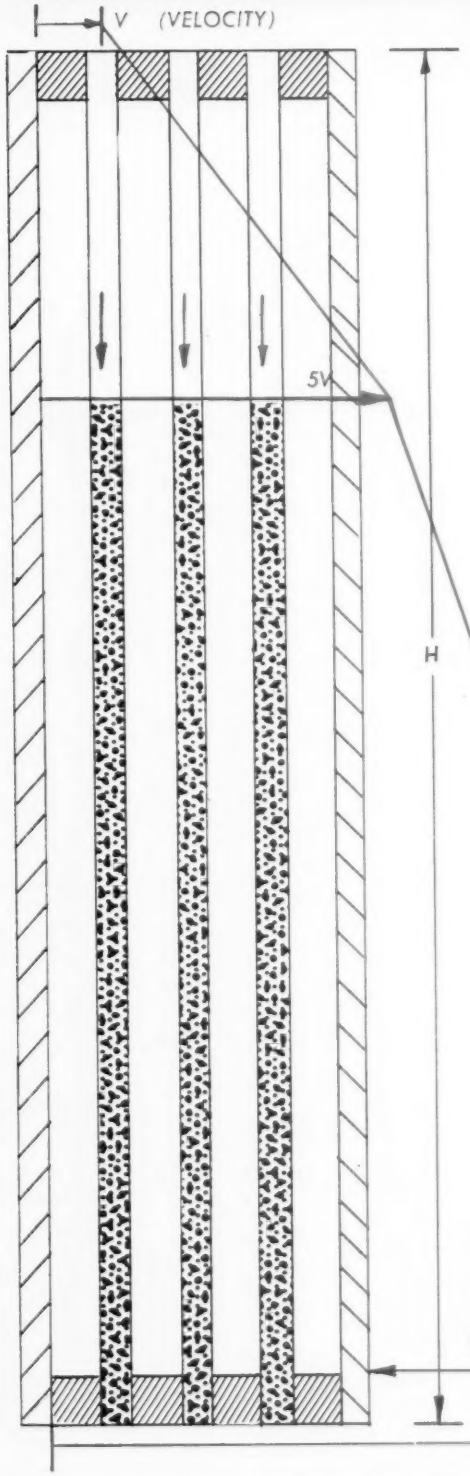

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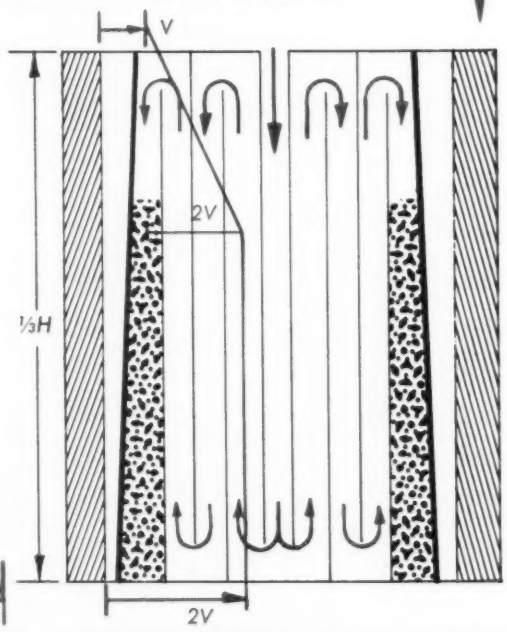

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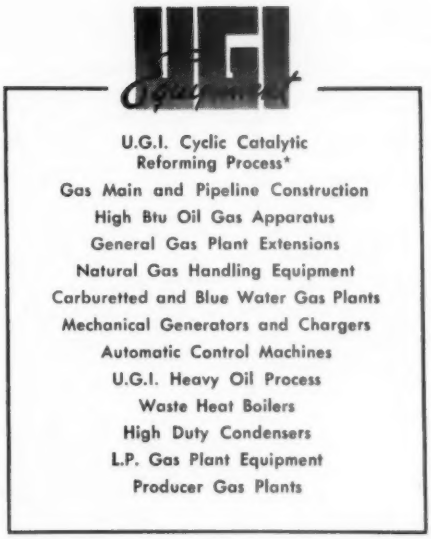

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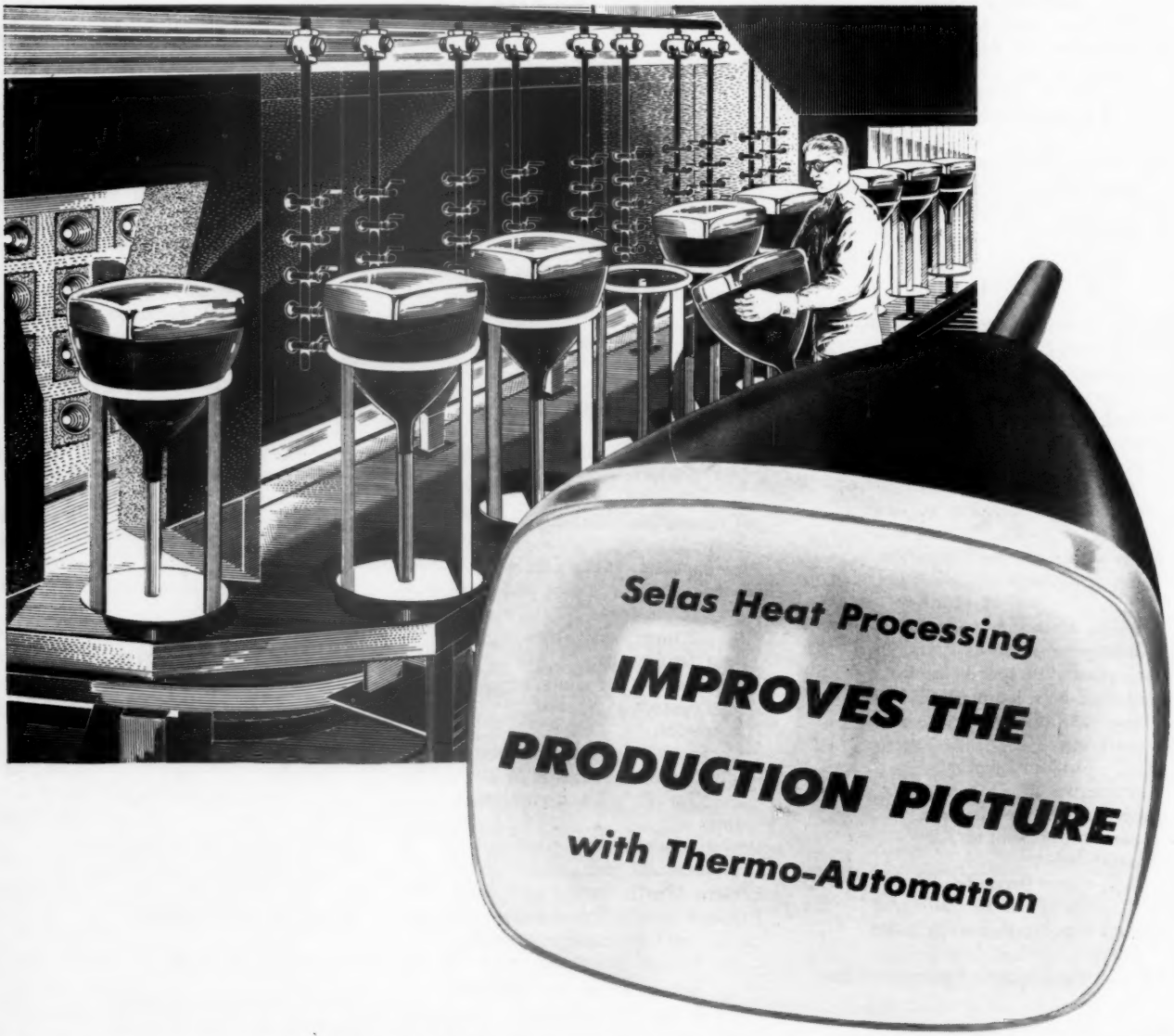
GAS CAN DO A BETTER JOB IN EVERY INDUSTRY



Control of heat . . . such as is possible only with gas . . . to get the right amount, at the right time and place, is important in processes where heat input must be patterned to the shape of the material to be heated.

TV-tube making is just one example where Selas Heat Processing is employed to improve quality and increase production by precisely and uniformly applying heat in accordance with optimum heating cycles.

Such benefits are typical of results with Selas continuous heat processing methods . . . in glass and ceramics, metals, petroleum refining, chemicals, paints, printing, plastics, textiles . . . in fact, virtually all industries.

Selas gas-fired heating is the key to improved efficiency in any heat processing operation. Selas engineers design equipment to help speed production, improve product quality and reduce manufacturing costs.

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SELAS

SELAS CORPORATION OF AMERICA • PHILADELPHIA 34, PA.

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STEEL PLATE DIVISION

LANCASTER – PENNA.

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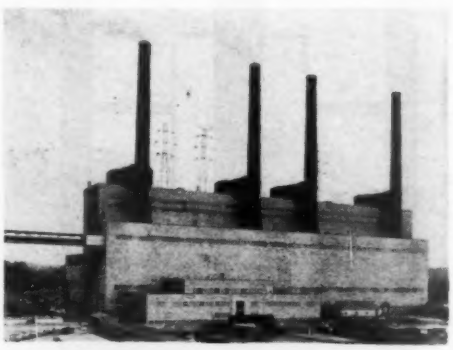
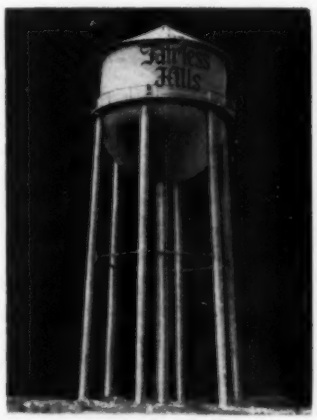
Posey Iron builds high and low pressure vessels for both liquids and gas.

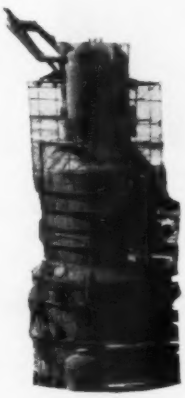
Posey Iron stainless clad digester is shown mounted on truck enroute to user. 13' O. D. x 40' long.



These four stacks by Posey Iron measure 23' diameter by 192'-6" high.

250,000 gallon water tank stands 105 feet above ground. Supplied with water from wells 65 to 75 feet underground.



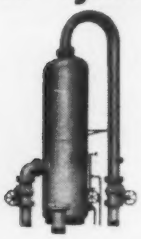


Vacuum tower for crude distilling fabricated throughout by Posey Iron Works.

Horizontal storage tanks being loaded aboard freighter for export. Many Posey Iron installations are overseas.

DIVISIONS: BRICK MACHINERY • FOUNDRY • HEATING • IROQUOIS • SHIPBUILDING • STEEL PLATE

BLAW-KNOX gas cleaners thoroughly scrub gas with oil no screens to clog no cyclones to fail



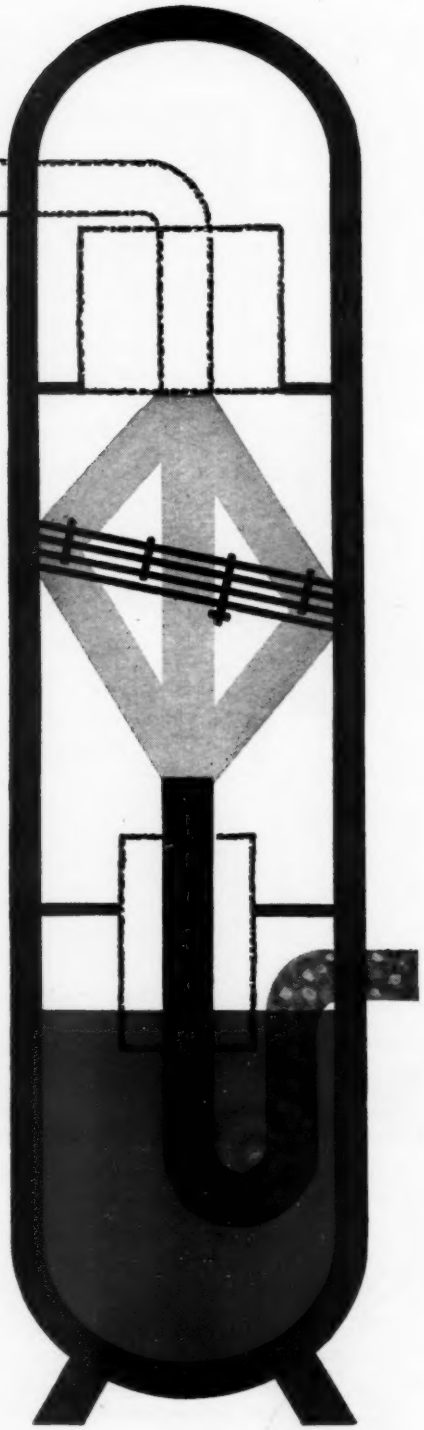
Blaw-Knox Gas Cleaners are engineered and built to remove dusts of all sizes under the most severe operating conditions with an absolute minimum of attention. There are no screens to clog or cyclones to errode and fail, reducing operating efficiency.

Immediately upon entering a Blaw-Knox Gas Cleaner, dust is violently, intimately washed with oil. The major portion of the heavier dust particles are actually scrubbed from the gas during this initial stage.

Remaining tiny wet dust particles are caught and agglomerated by a multiple baffle, primary separator. This separator is kept clean and operating at peak efficiency by continual recirculation of oil which washes particles down into a dust reservoir.

Finally, the gas flows through another expansion separation stage and into a multiple vane extractor which scrubs it clean of oil mist.

Traveling at high velocities, microscopic particles of pipeline dust sandblast regulators, compressor parts and metering devices, resulting in replacement costs, loss of revenue and customer ill will. Clean gas costs you less. So, when you buy, specify a Blaw-Knox Gas Cleaner and be sure that you're removing dusts of all sizes.



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BELL TELEPHONE SYSTEM

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Nothing is left to chance at Pipe Line Service to give customers uniform, high-quality protection for steel pipe. All equipment used has been developed by PLS engineers for maximum efficiency and economy in cleaning, priming, coating and wrapping.

Typical of the precision techniques employed is the coating and wrapping operation illustrated here. The pipe is propelled by positive-drive units which control the forward spiral movement of the pipe through the coating machine. This insures uniform lap of wrappers at all times.

Precision equipment like this is operated by trained personnel *inside* our plants to avoid delays caused by weather conditions. These factors add up to PLS *controlled* service which gives you more for your money in pipe protection.

PLS

Dependable Service Since 1931

PIPE LINE SERVICE CORPORATION

Pioneers in Steel Pipe Protection

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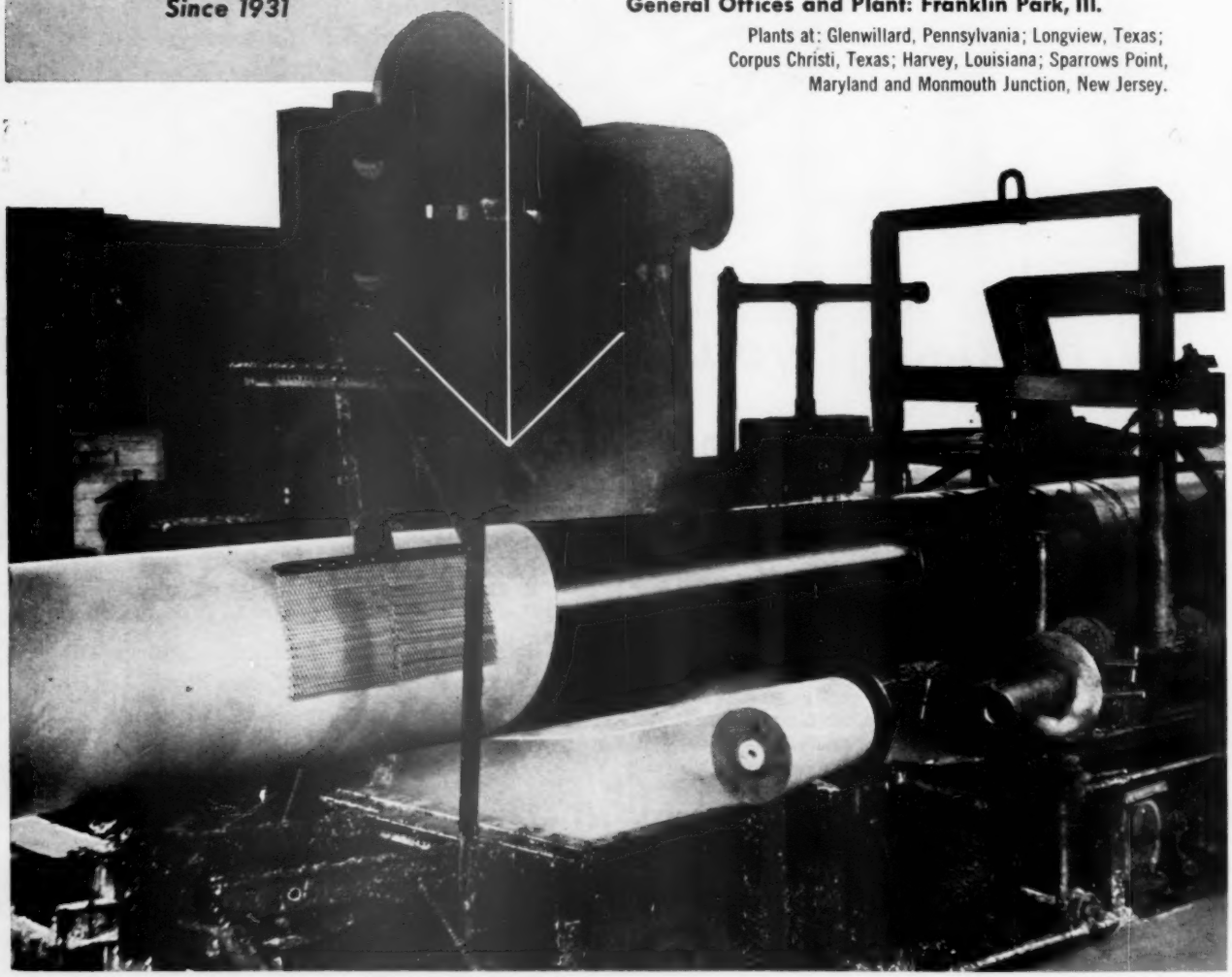

GLOSSARY OF GAS INDUSTRY TERMS

A

Absolute pressure: Gauge pressure plus atmospheric pressure.

Absorption: The extraction, from an atmosphere or mixture of gases or liquids, of one or more fluids, by the substance of a porous material with which the atmosphere, gases or liquids come in contact.

Adsorption: The extraction, from an atmosphere or mixture of gases or liquids, of one or more fluids, by surface adhesion to the material with which the atmosphere, gases or liquids come in contact.

After-cooler: Heat exchanger used to cool gas after it has been compressed.

Ambient temperature: The temperature of the air, atmosphere or other fluid that completely surrounds the apparatus, equipment or the work-piece under consideration.

Ampere: Practical unit of current and is that current which flows through a conductor having a resistance of 1 ohm and a difference of potential of 1 volt between its ends.

Anode: Positive pole in an electrolytic system, such as applied in cathodic protection; the electrode at which oxidation or corrosion occurs. See also Cathode and Cathodic protection.

Anodic coating: Protection of a metal by providing for preferential chemical attack through the formation of an electrochemical couple. A coating of zinc on steel is typical.

B

Back-fill: Earth which has been replaced in a ditch or trench after pipe or other device has been installed.

Back-fire: An explosion that takes place when too much primary air is mixed with gas, forming an explosive mixture which, igniting from the burner, burns in the mixing chamber.

Back-pressure: Pressure against which a fluid is flowing may be compounded of friction in lines, restrictions in pipes, valves, pressure in vessel to which fluid is flowing, hydrostatic head, or other impedient which causes resistance to fluid flow.

Barometric pressure: The pressure of the atmosphere as determined by a barometer.

Bell Hole: An enlarged hole dug in a trench to allow room for workmen to make a joint in pipe, such as caulking bell and spigot pipe or welding steel pipe.

Blue Flame: Gas flame in which combustibles are completely consumed, leaving no luminous carbon particles to impart yellow or orange color.

Blue gas: Also called water gas. Made in a cyclic process in which a fuel bed is alternately subjected to blast of air and steam.

Booster: A blower or compressor used to raise pressure or increase flow in a gas or air pipe line.

Bottled gas: Liquefied petroleum gas contained under high pressure in cylinders, for convenience in delivering to customers.

Btu: One British thermal unit, or Btu, is 1/180 of the heat required to raise the temperature of one pound of water from 32° to 212° F, a rise of 180° F.

Btu per cubic foot: A measure of the heat available or released when one cubic foot of a gas is burned.

By-product coke oven plant: A plant primarily for production of coke in which the gas produced is of secondary importance and hence a by-product.

C

Cap. A cup-shaped fitting placed on the end of a pipe to seal the pipe, usually threaded on the inside and screwed over end of pipe. Also, the act of placing a cap on a pipe.

Carbonization: Driving off volatile components of coal by the application of heat, leaving carbon behind.

Carbureted water gas: Also called carbureted blue gas, it is the result of enrichment of water gas by adding oil gas, natural gas or similar hydrocarbon. Generally, carbureted water gas is made to have a heating value of 525 to 550 Btu per cubic foot.

Catalytic cracking: The decomposition or breaking down of oil or hydrocarbons through the action of a catalyzer.

Cathode: The negative pole in an electrolytic system, such as applied in cathodic protection; oxidation, or corrosion, does not occur at this electrode.

Cathodic protection: A method of preventing the corrosion or deterioration of underground pipe and connected equipment, through the control of electrolysis.

City gate: The point or measuring station at which a distributing gas utility receives gas from a natural gas pipe line company.

Coal gas: Also called coke oven gas; it is manufactured by destructive distillation of bituminous coal in a gas retort or by-product coke oven.

Cock: A type of valve in which a tapered plug with a perpendicular hole through it is set into a tapered hole in the body of the valve. Holes are drilled through opposite sides of the body to line up with the hole in the plug.

Coke: The remaining hard porous substance left after coal gas has been removed from bituminous coal.

Combination utility. A utility that supplies gas and, generally, electricity to consumers.

Combustible gas indicator: An instrument designed for the detection of the presence of combustible gases in an atmosphere.

Combustion products: Also referred to as products of combustion, these are the unconsumed or remainder of a fuel after combustion; in gas combustion, generally, the combustion products are flue gases and water vapor.

Condensate, condensation: Condensate is the liquid resulting when a vapor is converted by cooling or application of pressure. Condensation is the liquid accumulating on cold surfaces in contact with moist vapors.

Conductivity: The rate at which a material permits heat to pass through it, expressed in Btu per hour, per square foot of surface, per foot or inch of thickness, with a 1 F temperature difference across the thickness.

Cubic foot, standard: The volume of gas saturated with water vapor which at 60° F and a pressure of 30 inches of mercury occupies one cubic foot. In the natural gas industry, generally, gas volumes are calculated on a dry basis at 60° F and a specified base pressure.

Curb cock: A shut-off valve in a gas service line, usually between the curb and the consumer's property line.

Customer density: Number of customers in a given unit of area or on a given length of distribution line.

D

Daily average send-out: The total volume of gas delivered for a period of time divided by number of days in the period.

Daily peak: The maximum volume of gas delivered in any one day.

Degree day: A term used to express the intensity of the heating season. It is the difference between 65 F and the daily mean temperature. The sum of these differences for every day of the heating season is the total degree days.

Dehumidification: The process of reducing the water vapor content of air or gas.

Dehydration: In general, the process of removing water, in all its forms, from solids or fluids .

Demand: The volume per unit of time at which a customer uses gas, averaged over a period of time.

Distribution company: A gas utility company that obtains its major gas operating revenue from retail gas sales to ultimate consumers.

Distribution losses: The amount of gas lost through leakage or condensation in delivering gas to customers through pipe lines.

Distribution system: The mains, service piping and equipment operated by a distribution company to deliver gas from local points of supply or manufacture to the customers' meters.

Drip: A low collection point installed in a gas line to which liquids, such as condensation, tend to flow and from which they cannot return to the pipe, but are discharged automatically or drained by a manually-operated valve.

E

Easement: A formal permission granted by landowners for laying and maintaining a gas pipe line.

Enrichment: The process of mixing a gas that has a relatively high heating value with another gas that has a lower value to raise the value of the latter gas.

Explosion head: A term applied to a protective device that is arranged to blow out a disk, usually, if an air-gas mixture explodes in a piping system.

Explosive limit: The high and low proportions of air-gas mixtures within which the mixtures are explosive when ignited.

F

Feed points: Connections between gas feeder lines and distribution networks in local gas distribution.

Filter: A mechanical means of removing solid materials from a liquid or gas; so constructed that the fluid passes through the filter and the solids are held back.

Fire valve: A safety valve installed at the inlet of gas meters set inside buildings and so designed that the gas supply will be shut off when the valve is heated to a certain temperature.

Fixation, fixing: The application of heat to transform an oil vapor into a gas.

Flame front: The base of a flame at which combustion starts.

Flash back: The burning of gas in the mixing chamber of a burner, or in a piping system, due to an excess of primary air or to slowness of gas flow.

Floating flame (flame blow-off): A flame that burns above the burner tip with a section of unburned gas between; caused by too great a gas velocity out of the burner tip.

F.O.T. efficiency: Fuel-oil-tar efficiency. The efficiency of a carbureted water gas plant, measured as the ratio of the heating value of the gas and tar produced to the heating value of the fuel and oil consumed, per unit volume of gas produced.

Foul gas: Unpurified manufactured gas.

Fuel value: A measure of the amount of heat available from the combustion of a unit weight or unit volume of a fuel. Usually expressed as Btu per pounds or per cubic foot.

Fuel-automatic cut-off protection: An automatic control on a gas-using appliance which shuts off the gas to the unit if the pilot light flame goes out.

G

Galling: The peeling or stripping of pipe threads.

Gang pusher: A supervisor in charge of a work gang.

Gas bag: A gas-proof, inflatable bag which can be inserted in a gas pipe and inflated to seal off the flow of gas in the pipe.

Gas conditioning: The removal of objectionable constituents and addition of such desirable constituents as odorants, water vapor and fogging oil.

Gas gravity: The ratio of the weight of volume of gas to the weight of an equal volume of dry air both volumes being measured at the same temperature and pressure.

Gas holder: A gas-tight shell for gas storage.

Gas hydrate: An objectionable frost-like formation that occurs when natural gas containing water vapor is subject to pressure.

Gas scrubber: Equipment for washing objectionable impurities and foreign substances from gas.

Gas service: The general term for serving the customer with gas; also, the pipe connection from a distribution gas main to a customer's meter.

Gasification: The conversion of another fuel into gas or the extraction of gas from another fuel.

Girbotol process: Removal of carbon dioxide and hydrogen sulfide from gas by washing with an amine solution.

Governor: Any device that controls the limits of an operating variable of a machine or process. In gas operation, a governor which maintains a predetermined level of pressure in a gas piping system is also called a regulator.

Gravity API: American Petroleum Institute index of weight of a unit volume of a liquid at 60 F.

$$\text{Degrees API} = \frac{141.5}{\text{Sp. gr. } 60/60^\circ \text{ F}} - 131.5$$

H

Heat of vaporization: The heat lost or gained in a substance passing from a vapor to a liquid or a liquid to vapor, with no change in temperature.

Heat transfer co-efficient. The quantity of heat transferred through a unit area of a material, in a unit of time and per unit of temperature difference between the two sides of the material.

High Btu oil gas process: A manufactured gas process in which oil is converted into a fuel gas having a higher heating value than that of coal gas or carbureted water gas. Often called Hi-Btu.

High-Low: A term for a type of heater control in which the main burner flame turns to a low position instead of going out when the controlled high temperature has been reached by means of the high flame.

Holiday: A break in the anti-corrosion coating of a pipe line, which leaves bare pipe exposed.

Humidifier: A mechanical means of increasing the relative humidity to a preset percentage in a closed chamber by injecting water vapor in air.

I

Ignition temperature: The temperature at which a combustible substance will start to burn and continue burning with a normal supply of air.

Illuminants: The group of hydrocarbons in a manufactured gas, such as ethylene and benzene, which burn with a luminous flame.

Illuminating gas: Natural or manufactured gas burned in a jet with a deficiency of primary air to produce a luminous flame for lighting.

Injection tube: A tube with a venturi throat which leads from the primary air port and gas orifice of a gas burner to mixing chamber and burner ports.

Insulating material: Any material of low thermal conductivity used to reduce the flow of heat.

J

Joint: A single length of pipe or tubing. A connection between two lengths of pipe.

K

Kelvin scale: A temperature scale based on the average kinetic energy per molecule of a perfect gas and having zero on the scale at 273.8 degrees below zero, Centigrade.

Kilogram-calorie (KC): The amount of heat necessary to increase the temperature of a kilogram of water one degree Centigrade.

Kilowatt: A unit of electrical energy equivalent to 1,000 watts, or approximately 1⅓ horsepower.

L

Lagging: Asbestos and magnesia plaster used on process equipment and piping as a thermal insulation.

Lay in: Place a pipe line in its ditch.

Leak clamp: A clamp used to press a gasket against a leaking section of pipe or pipe joint to seal the leak.

Leduc's rule: The volume of a gas mixture is equal to the sum of the volumes that would be occupied by each of the components of the mixture if at the temperature and pressure of the mixture.

Line fittings: Fittings used in piping to change the direction of the pipe line or divide the flow between two or more pipes; include elbows, tees, crosses and y's.

Liquefied petroleum gases: LP gases or LPG petroleum hydrocarbons of the paraffin series, normally gaseous, such as propane, butane, and iso-butane, but which can be compressed to liquid form.

Load: The rate of gas utilization per unit of time for a given system or point in a system. To load a governor means to set the governor to maintain a given pressure at that point as the rate of gas flow through the governor varies.

Load center: The geographic center for all gas loads of a specified system or area.

Load density: The concentration of gas load for a given area expressed as gas volume per unit of time and per unit of area.

Load factor: The ratio of the average volume of gas transported by a gas system, or segment of that system, during a specified time interval to the maximum volume transported during a comparable time interval. Load factors may be hourly, daily, weekly, monthly or annual.

M

Main extension: Gas mains added to an existing distribution system to serve new customers.

Manufactured gas: A combustible gas mixture produced synthetically in a gas plant and used as a fuel; also called city gas.

Meter books: Books in which successive readings of utility customers' meters are recorded by gas utility meter readers. The difference between successive readings is the gas consumption for the period.

Meter Density: The number of meters per unit of area or per unit length of distribution main.

Meter prover: A device for testing the accuracy of a gas meter.

N

Natural gas: Combustible gaseous hydrocarbons occurring naturally in the earth's formations and formed in past geologic ages.

O

Oakum: Shredded hemp fibers used to caulk or fill joints such as in bell and spigot pipe; oakum may be dry or saturated with tar or oil.

Odorant: Substance giving a readily-perceptible odor at low concentrations in the material into which it is mixed and used as a warning sign of the presence of the material, such as natural gas.

Off-peak: The period during a way, week, month or year when the load being delivered by a gas system is not at or near the maximum volume delivered by that system.

Ohm: Practical unit of electrical resistance and is equal resistance through which the fall of potential is 1 volt when the current strength is 1 ampere.

Oil fogging: Spraying a fine mist of oil into a gas stream of a distribution system to avoid the usually drying effect of gas in certain distribution and utilization equipment.

Oil gas: Gas produced by cracking a vaporized oil and fixing the vapors into a permanent gas at ordinary temperatures and pressures.

Oil reforming: Step in producing carbureted water gas in which a fraction of the carburetion oil is cracked to useful gas in the water gas generator.

Orifice meter: Meter for measuring flow of fluid through a pipe or duct by measurement of the pressure differential across a plate having a precisely-cut hole in its center.

Orsat analyzer: Apparatus used to measure the quantitative amounts of carbon dioxide (CO_2), oxygen (O) and carbon monoxide (CO) in a gas.

P

Pascal's law: A pressure exerted on a confined liquid is transmitted in all directions throughout the liquid.

Peak shaving. Supplying gas to a system from an auxiliary source, during periods of maximum demand, to reduce the load or demand on the primary source of supply.

Perfect gas: Any gas which conforms to Boyle's Law under wide variation of conditions, such as a gas in which the product of the absolute pressure, P, times the specific volume, v, divided by the absolute temperature, T, equals a constant, $R. \frac{Pv}{T} = R$

$_p$H number: A numerical designation of the degree of alkalinity of acidity of a substance. A $_p$H number of 7 denotes neutrality, numbers greater than 7 denote increasing alkalinity, numbers decreasing from 7 denote increasing acidity.

Pig: Cleaning device which is sent through a pipe line to scrape and brush foreign deposits, rust and dirt from the inside surface of the pipe; also called a go-devil.

Plenum chamber: Gas or air chamber under pressure and connected with one or more distributing ducts.

Pressure loader: Device in which the rate of gas flow controls the operation of a pressure governor.

Pressure regulator: Device which maintains a constant pressure in a fluid flow line, less than its inlet pressure, regardless of the rate of flow in the line.

Pressure survey: An investigation of gas pressures in various parts of a distribution system to insure that the pressure is adequate in all parts of the system for proper gas service.

Producer and producer gas: Machinery and equipment for burning or combustion of coal or coke with an insufficient supply of air to form producer gas which consists largely of carbon monoxide.

Production period: Period in water gas production in which steam is blown over the incandescent fuel bed to produce water or blue gas.

Purge: To thoroughly clean a pipe line or piece of equipment so that all the material it contained is removed.

Q

Quenching tower: An elevated water tank under which cars of hot coke can pass and have water sprayed on them to cool the coke.

R

Rate of flame propagation: The speed of flame-travel in an inflammable gaseous mixture of fuel and air.

Refrigeration ton: 200 Btu per minute of heat removal.

Regeneration: A unit of a coke oven plant containing two sections, each containing brick checker-work. Hot flue gases are passed alternately through the sections to heat the brick, after which the air to burn the producer gas is passed over the brick to preheat the air.

Relative humidity: The ratio of the volume of water vapor in the atmosphere to the volume the air would hold if completely saturated at that temperature. Usually expressed as a percentage.

Relief valve: A valve designed to quickly reduce the pressure-differential across it when such differential exceeds the predetermined maximum.

Rich gas: The relatively-high heating value gas that is made in the first part of the carbonizing period in a coke oven or coal gas retort.

Riser pipe: A straight vertical run of pipe.

Rotary displacement meter: A positive-pressure blower used as a meter in which gas pressure turns the blower and the quantity of gas passing through is proportional to the number of revolutions.

Rpm: Revolutions per minute.

S

Saddle: A fitted plate, held in place by clamps, straps or welding, over a hole in a gas main, and into which a branch line or customer-service connection is screwed.

Safety cut-off pilot or valve: An automatic valve controlling the flow of gas to an appliance burner and so arranged that the gas supply will be shut off if the pilot-flame goes out for any reason.

Service cock: A small plug valve located just ahead of a gas meter and used to shut off the gas flow to the meter and the customer's piping.

Service connection: The connecting piping between a gas main and the customer's meter.

Service tee: A tee in a customer's service piping with one leg closed and used for access to the service pipe in case of plugging with solids.

Slippage: The extent to which a meter registers less than the correct volume passing through the meter.

Soft flame: A gas flame with a relatively small amount of primary air.

Specific gravity: The ratio of the weight of a unit volume of a substance to the weight of the same volume of a reference substance, both at specified physical conditions.

Specific heat: The heat required to raise a unit mass of a substance through a degree of temperature difference.

Specific volume: The volume of a unit weight of a substance under specific conditions of temperature and pressure.

Specific weight: Weight per unit volume of a substance.

Sponge: A mixture of iron oxide and wood shavings for the removal of hydrogen sulfide from manufactured gas.

Spud: The small plug, with an orifice through it, which admits gas into the mixing chamber of a burner.

Stack loss: The flue gas loss; the sensible heat lost up the chimney in the dry flue gas; the sensible and latent heat of the water vapor contained in the flue gas.

Standard conditions: The basic temperature and pressure for measurement of gas volumes: 14.7 pounds per square inch (30 inches of mercury column) and 60 degrees F.

Standard metering base: Standard conditions, plus agreed corrections, to which all gas volumes are corrected for purposes of comparison and payment.

Sutherland law: Expresses the viscosity coefficient to a gas in terms of its absolute temperature.

Swing connection: The combination of a street tee and a street ell which will swing up or down slightly for aligning with surface pipe and absorbing traffic viberations.

T

Temperature: Basically the degree of heat above absolute zero. A measure of the quantity of heat contained in a substance.

Terzian factor: A factor based on the amount of oil and fuel used and the heating value of gas produced, to compare operating results of carbureted water gas plants.

Theoretical air: The chemically-exact volume of air necessary for the complete combustion of a specific amount of a fuel.

Therm: A quantity of heat equal to 100,000 Btu.

Thermostat: An automatic device which controls the temperature at its location by actuating and stopping the devices that supply fuel to the heating equipment.

Ton: A unit of weight equal to 2,000 pounds.

Turbulence: A condition of fluid flow in which the movement of a given particle of the fluid is constantly changing both in direction and velocity.

U

U-gauge: A U-shaped glass tube containing water or mercury and used to measure small pressures or presusre differences. One side of the U is connected to the pressure source and the other side left open or connected to another point in a system.

Underground storage: The storage of gas, natural or LP, in natural underground reservoirs at a different location from which it was originally produced. This is done for more efficient utilization of pipe lines and more economic deliveries to markets.

Up run: The part of the blue (water) gas production cycle in which steam is blown upwards through the generator.

V

Valve control: A fuel-air ratio control system which operates by means of mechanical linkage of related valves.

Venturi meter: A fluid-flow meter in which the rate of fluid-flow is determined by measuring the pressure drop caused by the flow of the fluid through a Venturi throat or tube. The pressure drop across the tube is proportional to the fluid flow rate.

Volatility: The relative ease with which a liquid can be vaporized.

Volt: Measure of electrical "pressure" or electro-motive force. Mathematically, it is the product of electrical resistance and electrical current. Volt = Resistance $\times$ Current.

W

Waste gas: The gaseous combustion products, such as carbon dioxide and nitrogen, which leave the combustion zone and are discharged to the surrounding atmosphere.

Watt: A practical unit of power and is produced when 1 ampere flows under an electromotive force of 1 volt.

Welded pipe: Skelp shaped into tubular form and welded along the edges to form a tube or pipe.

Wet bulb temperature: Temperature indicated by a thermometer having a water-saturated wick surrounding the bulb.

Wet drum meter: A large-capacity gas meter consisting of a cylindrical drum mounted to revolve inside a shell half-filled with water.

Working pressure: The pressure at which a piece of equipment normally operates.

X

Xylene: A coal tar derivative, higher boiling and slower evaporating than benzine or toluene.

Z

Zero gas: Gas at atmospheric pressure.

Weights and Measures

English Units

Length

1000 mils = 1 inch
12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 mile
4 inches = 1 hand
9 inches = 1 span
2½ feet = 1 pace
16½ feet or 5½ yards = 1 rod
1 knot or nautical mile = 6080.26 feet = ⅛ league
7.92 inches = 1 link
25 links = 1 rod
100 links or 66 feet or 4 rods = 1 chain
10 chains = 1 furlong
8 furlongs = 1 mile

Surface

144 square inches = 1 square foot
9 square feet = 1 square yard
30¼ square yards = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile
625 square links = 1 square rod
16 square rods = 1 square chain
10 square chains = 1 acre
640 acres = 1 square mile
36 square miles = 1 township

Volume

1728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard
128 cubic feet = 1 cord
24¾ cubic feet = 1 perch

Troy Weight

24 grains (gr.) = 1 pennyweight (dwt.)
20 pennyweights = 1 ounce (oz.)
12 ounces = 1 pound (lb.)

Avoirdupois Weight

16 drams (dr.) = 1 ounce (oz.)
16 ounces = 1 pound (lb.)
25 pounds = 1 quarter (qr.)
4 quarters = 1 hundred weight (ewt.)
20 hundred weight (2000 pounds) = 1 ton (T.)

Apothecaries' Weight

20 grains (gr.) = 1 scruple (sc.)
3 scruples = 1 dram (dr.)
8 drams = 1 ounce (oz.)
12 ounces = 1 pound (lb)

Dry Measure

2 pints (pt.) = 1 quart (qt.)
8 quarts = 1 peck (pk.)
4 pecks = 1 bushel (bu.)
36 bushels = 1 chaldron (ch.)

Liquid Measure

4 gills (gi.) = 1 pint (pt.)
2 pints = 1 quart (qt.)
4 quarts = 1 gallon (gal.)
31½ gallons = 1 barrel (bar.)
63 gallons = 1 hogshead (hhd.)

Apothecaries' Fluid Measure

60 minims = 1 fluid-drachm
8 fluid-drachms = 1 fluid-ounce
16 fluid-ounces = 1 pint
8 pints = 1 gallon

Circular Measure

60 seconds (″) = 1 minute (′)
60 minutes = 1 degree (°)
30 degrees = 1 sign (s)
12 signs, or 360 degrees = 1 circle (cir.)

Metric Units

Length

Centimeter	=	0.3937 inch.
Meter	=	3.28 feet.
Meter	=	1.094 yards.
Kilometer	=	0.621 statute mile.
Kilometer	=	0.5396 nautical mile.
Inch	=	2.540 centimeters.
Foot	=	0.305 meter.
Yard	=	0.914 meter.
Statute mile	=	1.61 kilometers.
Nautical mile	=	1.853 kilometers.

Area

Square centimeter	=	0.155 square inch.
Square meter	=	10.76 square feet.
Square meter	=	1.196 square yards.
Hectare	=	2.47 acres.
Square kilometer	=	0.386 square mile.
Square inch	=	6.45 square centimeters.
Square foot	=	0.0929 square meter.
Square yard	=	0.836 square meter.
Acre	=	0.405 hectare.
Square mile	=	2.59 square kilometers.

Volume

Cubic centimeter	=	0.0610 cubic inch.
Cubic meter	=	35.3 cubic feet.
Cubic meter	=	1.308 cubic yards.
Cubic inch	=	16.39 cubic centimeters.
Cubic foot	=	0.0283 cubic meter.
Cubic yard	=	0.765 cubic meter.

Capacity

Milliliter	=	0.0338 U. S. liquid ounce.
Milliliter	=	0.2705 U. S. apothecaries' dram.
Liter	=	1.057 U. S. liquid quarts.
Liter	=	0.2642 U. S. liquid gallon.
Liter	=	0.908 U. S. dry quart.
Dekaliter	=	1.135 U. S. pecks.
Hectoliter	=	2.838 U. S. bushels.
U. S. liquid ounce	=	29.57 milliliters.
U. S. apothecaries' dram	=	3.70 milliliters.
U. S. liquid quart	=	0.946 liter.
U. S. dry quart	=	1.101 liters.
U. S. liquid gallon	=	3.785 liters.
U. S. peck	=	0.881 dekaliter.
U. S. bushel	=	0.3524 hectoliter.

Weight

Gram	=	15.43 grains.
Gram	=	0.772 U. S. apothecaries' scruple.
Gram	=	0.2572 U. S. apothecaries' dram.
Gram	=	0.0353 avoirdupois ounce.
Gram	=	0.03215 troy ounce.
Kilogram	=	2.205 avoirdupois pounds.
Kilogram	=	2.679 troy pounds.
Metric ton	=	0.984 gross or long ton.
Metric ton	=	1.102 short or net tons.
Grain	=	0.0648 gram.
U. S. apothecaries' scruple	=	1.296 grams.
U. S. apothecaries' dram	=	3.89 grams.
Avoirdupois ounce	=	28.35 grams.
Troy ounce	=	31.10 grams.
Avoirdupois pound	=	0.4536 kilogram.
Troy pound	=	0.373 kilogram.
Gross or long ton	=	1.016 metric tons.
Short or net ton	=	0.907 metric ton.

PRESSURE CONVERSION TABLE

	Centimeters of water at 4°C	Inches of water at 4°C	Feet of water at 4°C	Centimeters of mercury	Inches of mercury	Grams per square centimeter	Ounces per square inch	Ounces per square foot	Pounds per square inch	Pounds per square foot	Dynes per square centimeter	Normal atmoshpere	45° Latitude atmosphere
Centimeters of water at 4°C	1.000000	0.3937000	0.03280833	0.07355393	0.02895818	0.9999730	0.2275682	32.76983	0.01422301	2.048114	980.6385	$0.0_39678148$	$0.0_39678632$
Inches of water at 4°C	2.540005	1.000000	0.08333333	0.1868273	0.07355393	2.539936	0.5780245	83.23552	0.03612653	5.202220	2490.827	0.002458255	0.002458377
Feet of water at 4°C	30.48006	12.00000	1.000000	2.241928	0.8826471	30.47924	6.936294	998.8263	0.4335183	62.42664	29889.92	0.02949906	0.02950053
Centimeters of mercury	13.59547	5.352535	0.4460446	1.000000	0.3937000	13.59510	3.093896	445.5211	0.1933685	27.84507	13332.24	0.01315789	0.01315855
Inches of mercury	34.53255	13.59547	1.132956	2.540005	1.000000	34.53162	7.858513	1131.626	0.4911570	70.72661	33863.95	0.03342112	0.03342279
Grams per square centimeter	1.000027	0.3937106	0.03280922	0.07355591	0.02895896	1.000000	0.2275744	32.77071	0.01422340	2.048169	980.6650	$0.0_39678410$	$0.0_39678893$
Ounces per square inch	4.394286	1.730031	0.1441692	0.3232170	0.1272505	4.394168	1.000000	144.0000	0.06250000	9.000000	4309.207	0.00425_28_56	0.004253068
Ounces per square foot	0.03051588	0.01201410	0.001001175	0.002244563	$0.0_38836843$	0.03051505	0.006944444	1.000000	$0.0_24340278$	0.06250000	29.92505	$0.0_42953372$	$0.0_42953520$
Pounds per square inch	70.30858	27.68049	2.306707	5.171473	2.036009	70.30669	16.00000	2304.000	1.000000	144.0000	68947.31	0.06804569	0.06804909
Pounds per square foot	0.4882541	0.1922256	0.01601880	0.03591300	0.01_413895	0.4882409	0.1111111	16.00000	0.006944444	1.000000	478.8007	$0.0_34725395$	$0.0_34725631$
Dynes per square centimeter	0.001019744	$0.0_24014731$	$0.0_33345609$	$0.0_47500616$	$0.0_42952992$	0.001019716	$0.0_22320613$	0.03341682	$0.0_41450383$	0.002088552	1.000000	$0.0_39869231$	$0.0_49869724$
Normal atmosphere	1033.255	406.7927	33.89939	76.00000	29.92120	1033.228	235.1361	33859.60	14.69601	2116.225	1013250.	1.000000	1.000050
45° latitude atmosphere	1033.204	406.7724	33.89770	75.99620	29.91970	1033.176	235.1244	33857.91	14.69527	2116.119	1013200.	0.9999500	1.000000

Expressions like 0.0_3 and 0.0_6 stand for 0.000 and 0.000000.
This table is based on the following values and definitions from I.C.T.:
Standard acceleration of gravity, 980.665 cm per second. 1 l = 1000.027 cc, 1 cm = 0.3937 in.
[1]Adapted from *K. C. Testing Lab. Bull.* 25.
Adapted from "International Critical Table," McGraw-Hill Book Co.
By permission from "Gas Engineers' Handbook." Copyright 1934, McGraw-Hill Book Company, Inc.

45° latitude acce'eration of gravity, 980.616 cm per second per second, 1 lb = 453.5924277 g. 1 normal atmosphere = pressure exerted on 1 sq cm by a vertical column of liquid 76 cm in height, of density 13.5951 g per cubic centimeter, at a place where the acceleration of gravity is standard.
45° latitude atmosphere differs from the normal atmosphere only in the value of gravity.

CONVERSION FACTORS FOR ENERGY UNITS

Acceleration of gravity = 980.665 cm per second per second

Units	Btu	Pcu[2]	Calories (large)	Foot-pounds	Foot-tons	Kilogram-meters	Horsepower-hours	Kilowatt-hours	Joules, inter-national	Pounds carbon[2]	Pounds water[2]
Btu	1.00000	0.555556	0.251983	777.979	0.388990	107.560	$0.0_3392922$	$0.0_3293000$	1,054.46	$0.0_4687569$	0.00103050
Pcu[2]	1.80000	1.00000	0.453569	1,400.36	0.700181	193.607	$0.0_3707260$	$0.0_3527400$	1,898.03	$0.0_3123762$	0.00185490
Calories (large)	3.96852	2.20474	1.00000	3,087.42	1.54372	426.853	0.00155932	0.00116278	4,184.66	$0.0_32272863$	0.00408958
Foot-pounds	0.00128538	$0.0_3714101$	$0.0_3323894$	1.00000	$0.0_3500000$	0.138255	$0.0_5505051$	$0.0_5376617$	1.35539	$0.0_7883788$	$0.0_3132459$
Foot-tons	2.57076	1.42820	0.647788	2,000.00	1.00000	276.510	0.00101010	$0.0_3753233$	2,710.77	$0.0_3176758$	0.00264918
Kilogram-meters	0.00929716	0.00516509	0.00234272	7.23300	0.00361650	1.00000	$0.0_3365306$	$0.0_3272407$	9.80351	$0.0_6639244$	$0.0_3958076$
Horsepower-hours	2,545.03	0.141391	641.304	1,979,980	989.999	273,743	1.00000	0.745694	2,683,640	0.174988	2.62266
Kilowatt-hours	3,412.97	1,896.09	860.009	2,655,220	1,327.61	367,098	1.34103	1.00000	3,598,850	0.234665	3.51707
Joules (international)	$0.0_3948350$	$0.0_3526861$	$0.0_3238968$	0.737797	$0.0_3368898$	0.102004	$0.0_3372628$	$0.0_3277867$	1.00000	$0.0_7652056$	$0.0_6977278$
Pounds carbon[2]	14,544	808.000	3,664.84	11,314,900	5,657.47	1,564,350	5.71466	4.26139	15,336,100	1.00000	14.9876
Pounds water[2]	970.40	539.111	244.524	754,951	377.476	104,376	0.381292	0.284327	1,023,250	0.0667217	1.00000

This table is based upon the following I.C.T. values:

1 Btu (mean)	= 1054.8	absolute joules
1 g-cal (mean)	= 4.186	absolute joules
1 ft-lb	= 1.35582	absolute joules
1 kg-m	= 9.80665	absolute joules
1 hp-hr	= $2.6845 \times 10_8$	absolute joules
1 kwhr	= $3.6000 \times 10_8$	absolute joules
1 international joule	= 1.00032	absolute joules

[1]Adapted from Van Nostrand's "Chemical Annual" and I.C.T.:
[2]Pcu refers to pound-Centigrade unit. The ton used is 2000 lb. "Pounds carbon" refers to pounds of carbon oxidized to Co_2 of 100 per cent efficiency equivalent to the corresponding number of heat units. "Pounds water" refers to pounds of water evaporated at 212° F at 100 per cent efficiency.
0.0_3 signifies 0.000.
1 cal (small) per gram = 1.8 Btu per pound.
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Temperature Conversion Table

°C	0	10	20	30	40	50	60	70	80	90
	F	F	F	F	F	F	F	F	F	F
—200	—328	—364	—364	—382	—400	—418	—436	—454	....	....
—100	—148	—166	—184	—202	—220	—238	—256	—274	—292	—310
—0	+32	+14	—4	—22	—40	—58	—76	—94	—112	—130
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1058	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1238	1256	1274
700	1292	1310	1328	1346	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1832	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794
2100	3812	3830	3848	3866	3884	3902	3920	3938	3956	3974
2200	3992	4010	4028	4046	4064	4082	4100	4118	4136	4154
2300	4172	4190	4208	4226	4244	4262	4280	4298	4316	4334
2400	4352	4370	4388	4406	4424	4442	4460	4478	4496	4514
2500	4532	4550	4568	4586	4604	4622	4640	4658	4676	4694
2600	4712	4730	4748	4766	4784	4802	4820	4838	4856	4874
2700	4892	4910	4928	4946	4964	4982	5000	5018	5036	5054
2800	5072	5090	5108	5126	5144	5162	5180	5198	5216	5234
2900	5252	5270	5288	5306	5324	5342	5360	5378	5396	5414
3000	5432	5450	5468	5486	5504	5522	5540	5558	5576	5594
3100	5612	5630	5648	5666	5684	5702	5720	5738	5756	5774
3200	5792	5810	5828	5846	5864	5882	5900	5918	5936	5954
3300	5972	5990	6008	6026	6044	6062	6080	6098	6116	6134
3400	6152	6170	6188	6206	6224	6242	6260	6278	6296	6314
3500	6332	6350	6368	6386	6404	6422	6440	6458	6476	6494
3600	6512	6530	6548	6566	6584	6602	6620	6638	6656	6674
3700	6692	6710	6728	6746	6764	6782	6800	6818	6836	6854
3800	6872	6890	6908	6926	6944	6962	6980	6998	7016	7034
3900	7052	7070	7088	7106	7124	7142	7160	7178	7196	7214
°C	0	10	20	30	40	50	60	70	80	90

°C	°F
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0

°F	°C
1	1.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

Examples: 1347° C = 2444° F +12.6° F = 2456.6° F. 3367° F = 1850° C + 2.78° C = 1852.78° C.

Bureau of Standards—M126

VISCOSITY CONVERSION TABLE

The following table will give a comparison of various viscosity ratings so that if the viscosity is given in terms other than Saybolt Universal, it can be translated quickly by following horizontally to the Saybolt Universal column.

Kinematic Viscosity Centipoises = K	Seconds Saybolt Universal	Seconds Saybolt Furol	Seconds Redwood	Seconds Redwood Admiralty	Degrees Engler	Degrees Barley
1.00	31	.....	29	.....	1.00	6200
2.56	35	.....	32.1	.....	1.16	2420
4.30	40	.....	36.2	5.10	1.31	1440
5.90	45	.....	40.3	5.52	1.46	1050
7.40	50	.....	44.3	5.83	1.58	838
8.83	55	.....	48.5	6.35	1.73	702
10.20	60	.....	52.3	6.77	1.88	618
11.53	65	.....	56.7	7.17	2.03	538
12.83	70	12.95	60.9	7.60	2.17	483
14.10	75	13.33	65.0	8.00	2.31	440
15.35	80	13.70	69.2	8.44	2.45	404
16.58	85	14.10	73.3	8.86	2.59	374
17.80	90	14.44	77.6	9.30	2.73	348
19.00	95	14.85	81.5	9.70	2.88	326
20.20	100	15.24	85.6	10.12	3.02	307
31.80	150	19.3	128	14.48	4.48	195
43.10	200	23.5	170	18.90	5.92	144
54.30	250	28.0	212	23.45	7.35	114
65.40	300	32.5	254	28.0	8.79	95
76.50	350	35.1	296	32.5	10.25	81
87.60	400	41.9	338	37.1	11.70	70.8
98.60	450	46.8	381	41.7	13.15	62.9
110.	500	51.6	423	46.2	14.60	56.4
121.	550	56.6	465	50.8	16.05	51.3
132.	600	61.4	508	55.4	17.50	47.0
143	650	66.2	550	60.1	19.00	43.4
154	700	71.1	592	64.6	20.45	40.3
165	750	76.0	635	69.2	21.90	37.6
176	800	81.0	677	73.8	23.35	35.2
187	850	86.0	719	78.4	24.80	33.2
198	900	91.0	762	83.0	26.30	31.3
209	950	95.8	804	87.6	27.70	29.7
220	1000	100.7	846	92.2	29.20	28.2
330	1500	150	1270	138.2	43.80	18.7
440	2000	200	1690	184.2	58.40	14.1
550	2500	250	2120	230	73.00	11.3
660	3000	300	2540	276	87.60	9.4
770	3500	350	2960	322	100.20	8.05
880	4000	400	3380	368	117.00	7.05
990	4500	450	3810	414	131.50	6.26
1100	5000	500	4230	461	146.00	5.64
1210	5500	550	4650	507	160.50	5.13
1320	6000	600	5080	553	175.00	4.70
1430	6500	650	5500	559	190.00	4.34
1540	7000	700	5920	645	204.50	4.03
1650	7500	750	6350	691	219.00	3.76
1760	8000	800	6770	737	233.50	3.52
1870	8500	850	7190	783	248.00	3.32
1980	9000	900	7620	829	263.00	3.13
2090	9500	950	8040	875	277.00	2.97
2200	10000	1000	8460	921	292.00	2.82

The viscosity is often expressed in terms of viscosimeters other than the Saybolt Universal. The formulas for the various viscosimeters are as follows:

Redwood	$K = .26\,t - \frac{188}{t}$	(British)	Saybolt Universal	$K = .22\,t - \frac{180}{t}$	American
Redwood Admiralty	$K = 2.396 - \frac{40.3}{t}$	(British)	Saybolt Furol	$K = 2.2\,t - \frac{203}{t}$	American
			Engler	$K = .147\,t - \frac{374}{t}$	German

$= \text{Engler Degrees} \times 51.3$

The Barbey measures the quantity of flow per hour under constant head instead of the time for a definite quantity under varying head as do the others.

The Saybolt Furol and Redwood Admiralty are especially designed for measuring the more viscous oils and give a reading in seconds approximately one-tenth of that given for the same oil by the Saybolt Universal and Redwood respectively.

If viscosity is given at any two temperatures, the viscosity at any other temperature can be obtained by plotting the viscosity against temperature in degrees Fahrenheit on special cross section paper. The points for a given oil lie in a straight line.

Courtesy Worthington Pump & Machinery Corp.

COMPARISON OF DEGREES BAUME AND API WITH SPECIFIC GRAVITY

The general relationship between degrees Baume′ and specific gravity is found in the following:

For liquids heavier than water—

$$\text{Sp. Gr.} = \frac{145}{145 - {}^\circ \text{ Baume}'} \text{ at } 60^\circ \text{ F.}$$

For liquids lighter than water—

$$\text{Sp. Gr.} = \frac{140}{130 + {}^\circ \text{ Baume}'} \text{ at } 60^\circ \text{ F.}$$

The corresponding relationship for degrees API is as follows.

$$\text{Sp. Gr.} = \frac{141.5}{131.5 + {}^\circ \text{ API}}$$

Specific Gravity			
Baumé			
Deg.	Liquids Heavier than Water	Liquids Lighter than Water	API
0	1.000		
1.0	1.007		
2.0	1.014		
3.0	1.021		
4.0	1.028		
5.0	1.036		
6.0	1.043		
7.0	1.051		
8.0	1.058		
9.0	1.066		
10.0	1.074	1.000	1.000
11.0	1.082	.993	.993
12.0	1.090	.986	.986
13.0	1.098	.979	.979
14.0	1.107	.972	.973
15.0	1.115	.965	.966
16.0	1.124	.959	.959
17.0	1.133	.952	.953
18.0	1.142	.946	.947
19.0	1.151	.940	.940
20.0	1.160	.933	.934
21.0	1.169	.927	.928
22.0	1.179	.921	.922
23.0	1.188	.915	.916
24.0	1.198	.909	.910
25.0	1.208	.903	.904
26.0	1.218	.897	.898

Specific Gravity			
Baumé			
Deg.	Liquids Heavier than Water	Liquids Lighter than Water	API
27.0	1.229	.892	.893
28.0	1.239	.886	.887
29.0	1.250	.880	.882
30.0	1.261	.875	.876
31.0	1.272	.870	.871
32.0	1.283	.864	.865
33.0	1.295	.859	.860
34.0	1.306	.854	.855
35.0	1.318	.848	.850
36.0	1.330	.843	.845
37.0	1.343	.838	.840
38.0	1.355	.833	.835
39.0	1.368	.828	.830
40.0	1.381	.823	.825
41.0	1.394	.819	.820
42.0	1.408	.814	.816
43.0	1.422	.809	.811
44.0	1.436	.805	.806
45.0	1.450	.800	.802
46.0	1.465	.795	.797
47.0	1.480	.791	.793
48.0	1.495	.786	.788
49.0	1.510	.782	.784
50.0	1.526	.778	.780
51.0	1.543	.773	.775
52.0	1.559	.769	.771
53.0	1.576	.765	.767

Specific Gravity			
Baumé			
Deg.	Liquids Heavier than Water	Liquids Lighter than Water	API
54.0	1.593	.761	.763
55.0	1.611	.757	.759
56.0	1.629	.753	.755
57.0	1.648	.749	.751
58.0	1.667	.745	.747
59.0	1.686	.741	.743
60.0	1.706	.737	.739
61.0	1.726	.733	.735
62.0	1.747	.729	.731
63.0	1.768	.725	.728
64.0	1.790	.722	.724
65.0	1.812	.718	.720
66.0	1.835	.714	.717
67.0	1.859	.711	713
68.0	1.883	.707	.709
69.0	1.908	.703	.706
70.0	1.933	.700	.702
71.0	1.959	.696	.699
72.0	1.986	.693	.695
73.0		.690	.692
74.0		.686	.689
75.0		.683	.685
76.0		.680	.682
77.0		.676	.679
78.0		.673	.675
79.0		.670	.672
80.0		.667	.669

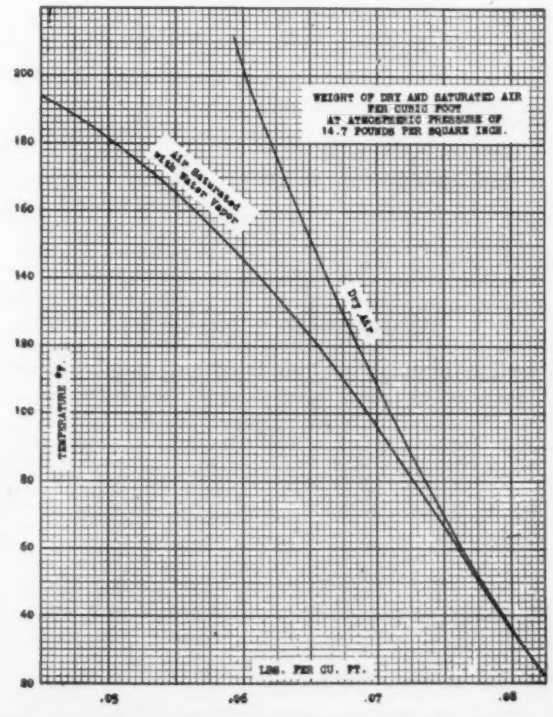
COMPOSITION OF AIR

	Dry Air[1]	Per cent by Volume Atmospheric Air at Sea Level (Average[2])
Nitrogen	78.03	77.08
Oxygen	20.99	20.75
Argon	.94	.93
Carbon Dioxide	.03	.03
Hydrogen	.01	.01
Water Vapor	—	1.20
Krypton, Neon, Niton, Xenon	Trace	Trace
	100.00	100.00

[1]International Critical Tables.

[2]Guide American Society of Heating and Ventilating Engineers.

WEIGHT OF DRY AND SATURATED AIR AT DIFFERENT TEMPERATURES IN LBS. PER CU. FT.



REDUCTION OF BAROMETRIC READINGS

This table gives the corrections in inches of mercury to convert readings at various temperatures to readings at standard temperature.

°F	Observed reading of barometer in inches						
	24	25	26	27	28	29	30
0	+0.063	+0.065	+0.068	+0.070	+0.073	+0.076	+0.078
2	+0.058	+0.061	+0.063	+0.065	+0.068	+0.070	+0.073
4	+0.054	+0.056	+0.058	+0.061	+0.063	+0.065	+0.067
6	+0.049	+0.052	+0.054	+0.056	+0.058	+0.060	+0.062
8	+0.045	+0.047	+0.049	+0.051	+0.053	+0.054	+0.056
10	+0.011	+0.042	+0.044	+0.046	+0.047	+0.049	+0.051
12	+0.036	+0.038	+0.039	+0.041	+0.042	+0.042	+0.045
14	+0.032	+0.033	+0.035	+0.036	+0.037	+0.039	+0.040
16	+0.028	+0.029	+0.030	+0.031	+0.032	+0.033	+0.034
18	+0.023	+0.024	+0.025	+0.026	+0.027	+0.028	+0.029
20	+0.019	+0.020	+0.020	+0.021	+0.022	+0.023	+0.024
22	+0.014	+0.015	+0.016	+0.016	+0.017	+0.017	+0.018
24	+0.010	+0.011	+0.011	+0.011	+0.012	+0.012	+0.013
26	+0.006	+0.006	+0.006	+0.006	+0.007	+0.007	+0.007
28	+0.001	+0.001	+0.001	+0.002	+0.002	+0.002	+0.002
30	−0.003	−0.003	−0.003	−0.003	−0.003	−0.004	−0.004
32	−0.007	−0.008	−0.008	−0.008	−0.009	−0.009	−0.009
34	−0.012	−0.012	−0.013	−0.013	−0.014	−0.014	−0.015
36	−0.016	−0.017	−0.017	−0.018	−0.019	−0.019	−0.020
38	−0.020	−0.021	−0.022	−0.023	−0.024	−0.025	−0.026
40	−0.025	−0.026	−0.027	−0.028	−0.029	−0.030	−0.031
42	−0.029	−0.030	−0.032	−0.033	−0.034	−0.035	−0.036
44	−0.033	−0.035	−0.036	−0.038	−0.039	−0.040	−0.042
46	−0.038	−0.039	−0.041	−0.043	−0.044	−0.046	−0.047
48	−0.042	−0.044	−0.046	−0.047	−0.049	−0.051	−0.053
50	−0.046	−0.048	−0.050	−0.052	−0.054	−0.056	−0.058
52	−0.051	−0.053	−0.055	−0.057	−0.059	−0.061	−0.064
54	−0.055	−0.057	−0.060	−0.062	−0.064	−0.067	−0.069
56	−0.060	−0.062	−0.064	−0.067	−0.069	−0.072	−0.074
58	−0.064	−0.066	−0.069	−0.072	−0.074	−0.077	−0.080
60	−0.068	−0.071	−0.074	−0.077	−0.080	−0.082	−0.085
62	−0.073	−0.076	−0.079	−0.082	−0.085	−0.088	−0.091
64	−0.077	−0.080	−0.083	−0.086	−0.090	−0.093	−0.096
66	−0.081	−0.085	−0.088	−0.091	−0.095	−0.098	−0.101
68	−0.085	−0.089	−0.093	−0.096	−0.100	−0.103	−0.107
70	−0.090	−0.094	−0.097	−0.101	−0.105	−0.109	−0.112
72	−0.094	−0.098	−0.102	−0.106	−0.110	−0.114	−0.118
74	−0.098	−0.103	−0.107	−0.111	−0.115	−0.119	−0.123
76	−0.103	−0.107	−0.111	−0.116	−0.120	−0.124	−0.128
78	−0.107	−0.112	−0.116	−0.120	−0.125	−0.129	−0.341
80	−0.111	−0.116	−0.121	−0.125	−0.130	−0.135	−0.139
82	−0.116	−0.121	−0.125	−0.130	−0.135	−0.140	−0.145
84	−0.120	−0.125	−0.130	−0.135	−0.140	−0.145	−0.150
86	−0.124	−0.130	−0.135	−0.140	−0.145	−0.150	−0.155
88	−0.129	−0.134	−0.139	−0.145	−0.150	−0.155	−0.161
90	−0.133	−0.138	−0.144	−0.150	−0.155	−0.161	−0.166
92	−0.137	−0.143	−0.149	−0.154	−0.160	−0.166	−0.172
94	−0.142	−0.147	−0.153	−0.159	−0.165	−0.171	−0.177
96	−0.146	−0.152	−0.158	−0.164	−0.170	−0.176	−0.182
98	−0.150	−0.156	−0.163	−0.169	−0.175	−0.181	−0.188
100	−0.154	−0.161	−0.167	−0.174	−0.180	−0.187	−0.193

From Table 44 of Smithsonian Meteorological Tables, 1939.
Example:

Observed height of barometer	= 29.502
Attached thermometer, 68 degrees F. Reduction for temperature	= 0.105
Barometer reading corrected for temperature	= 29.397

ATMOSPHERIC PRESSURE

This table is compiled from elevations and normal atmospheric pressures at United States Weather Bureau stations.

Elevation in feet	Inches mercury	Pounds absolute	Elevation in feet	Inches mercury	Pounds absolute
0	30.00	14.73	2000	27.90	13.70
100	29.89	14.68	2500	27.39	13.45
200	29.78	14.63	3000	26.90	13.21
300	29.67	14.57	3500	26.41	12.97
400	29.56	14.52	4000	25.93	12.74
500	29.45	14.46	4500	25.46	12.50
600	29.34	14.41	5000	25.00	12.28
800	29.13	14.31	5500	24.54	12.05
1000	28.93	14.21	6000	24.10	11.84
1500	28.41	13.95	6500	23.67	11.63

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ALTITUDE AND ATMOSPHERIC PRESSURE

This table from the United States Weather Bureau gives altitudes and average atmospheric pressures.

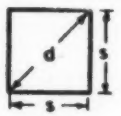
Location	Elevation in feet above sea level	Average atmospheric pressure pounds	Location	Elevation in feet above sea level	Average atmospheric pressure pounds
Abilene, Tex.	1738	13.85	Hartford, Conn.	159	14.66
Albany, N. Y.	97	14.70	Helena, Mont.	4110	12.67
Amarillo, Tex.	3676	12.90	Houston, Tex.	138	14.68
Asheville, N. C.	2253	13.62	Indianapolis, Ind.	822	41.32
Atlanta, Ga.	1173	14.16	Kansas City, Mo.	963	14.23
Atlantic City, N. J.	52	14.72	Keokuk, Iowa	614	14.42
Austin, Tex.	605	14.43	Knoxville, Tenn.	995	14.25
Baker, Ore.	3471	13.01	Lander, Wyo.	5372	12.10
Baltimore, Md.	123	14.69	Lincoln, Neb.	1189	14.11
Binghamton, N. Y.	871	14.29	Los Angeles, Cal.	338	14.55
Birmingham, Ala.	700	14.39	Louisville, Ky.	525	14.48
Bismarck, N. Dak.	1674	13.84	Madison, Wis.	974	14.23
Boise, Idaho	2739	13.35	Memphis, Tenn.	399	14.55
Boston, Mass.	125	14.67	Miami, Fla.	25	14.74
Brownsville, Tex.	57	14.69	Milwaukee, Wis.	681	14.38
Buffalo, N. Y.	767	14.33	Minneapolis, Minn.	918	14.23
Burlington, Vt.	403	15.51	Montgomery, Ala.	223	14.65
Cairo, Ill.	358	14.57	Nashville, Tenn.	546	14.48
Charleston, S. C.	48	14.74	New Orleans, La.	53	14.73
Charlotte, N. C.	779	14.36	New York, N. Y.	314	14.58
Chattanooga, Tenn.	762	14.37	North Platte, Neb.	2821	13.29
Cheyenne, Wyo.	6088	11.79	Oklahoma City, Okla.	1214	14.11
Chicago, Ill.	673	14.39	Omaha, Neb.	1105	14.16
Cincinnati, Ohio	627	14.43	Parkesburg, W. Va.	637	14.45
Cleveland, Ohio	762	14.34	Philadelphia, Pa.	114	14.70
Columbia, N. C.	784	14.34	Pittsburgh, Pa.	842	14.31
Columbus, Ohio	822	14.33	Pocatello, Idaho	4477	12.52
Concord, N. H.	289	14.57	Pueblo, Colo.	4685	12.42
Corpus Christi, Tex.	20	14.72	Rapid City, S. Dak.	3259	13.06
Dallas, Tex.	512	14.47	Reno, Neb.	4532	12.51
Dayton, Ohio	899	14.29	Rochester, N. Y.	523	14.46
Del Rio, Tex.	944	14.22	Roswell, N. Mex.	3566	12.95
Denver, Colo.	5292	12.14	Sacramento, Cal.	69	14.69
Des Moines, Iowa	861	14.29	St. Louis, Mo.	568	14.45
Detroit, Mich.	730	14.36	St. Paul, Minn.	837	14.28
Dodge City, Kan.	2509	13.46	Salt Lake City, Utah	4360	12.50
Dubuque, Iowa	700	14.37	San Antonio, Tex.	693	14.38
Duluth, Minn.	1133	14.12	San Diego, Cal.	87	14.68
Elkins, W. Va.	1947	13.77	San Francisco, Cal.	155	14.66
El Paso, Tex.	3778	12.86	Santa Fe, N. Mex.	7013	11.44
Erie, Pa.	714	14.37	Seattle, Wash.	125	14.69
Evansville, Ind.	431	14.53	Shreveport, La.	249	14.62
Fort Smith, Ark.	457	14.50	Spokane, Wash.	1929	13.74
Fort Wayne, Ind.	856	14.29	Syracuse, N. Y.	597	14.43
Fort Worth, Tex.	670	14.39	Toledo, Ohio	628	14.42
Grand Rapids, Mich.	707	14.37	Washington, D. C.	112	14.70
Harrisburg, Pa.	374	14.55	Yuma, Ariz.	141	14.61

MERCURY VACUUM — ABSOLUTE PRESSURE

Based on atmospheric pressure of 14.4 pounds and mercury at 32 degrees F.

Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute	Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute
1	28.32	13.91	16	13.32	6.54
2	27.32	13.42	17	12.32	6.05
3	26.32	12.93	18	11.32	5.56
4	25.32	12.44	19	10.32	5.07
5	24.32	11.94	20	9.32	4.58
6	23.32	11.45	21	8.32	4.09
7	22.32	10.96	22	7.32	3.59
8	21.32	10.47	23	6.32	3.10
9	20.32	9.98	24	5.32	2.61
10	19.32	9.49	25	4.32	2.12
11	18.32	9.00	26	3.32	1.63
12	17.32	8.51	27	2.32	1.14
13	16.32	8.01	28	1.32	0.65
14	15.32	7.52	29	0.32	0.16
15	14.32	7.03	30	....	....

AREAS AND VOLUMES



Square

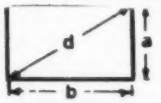
A = area.

$A = s^2$

$A = \frac{1}{2} d^2$

$s = 0.7071\ d = \sqrt{A}$

$d = 1.414\ s = 1.414\ \sqrt{A}$



Rectangle

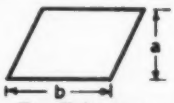
A = area.

$A = ab$

$d = \sqrt{a^2 + b^2}$

$a = A \div b$

$b = A \div a$



Parallelogram

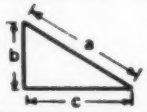
A = area.

$A = ab$

$a = A \div b$

$b = A \div a$

Note that dimension a is measured at right angles to line b.



Right-angled triangle

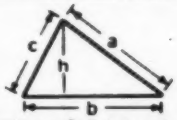
A = area.

$A = \frac{bc}{2}$

$A = \sqrt{b^2 + c^2}$

$b = \sqrt{a^2 - c^2}$

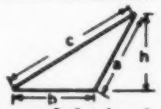
$c = \sqrt{a^2 - b^2}$



Acute-angled triangle

A = area.

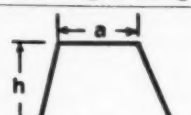
$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$$



Obtuse-angled triangle

A = area.

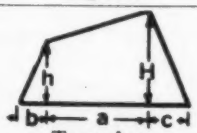
$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 - a^2 - b^2}{2b}\right)^2}$$



Trapezoid

A = area.

$$A = \frac{(a + b)\,h}{2}$$



Trapezium

A = area.

$$A = \frac{(H + h)\,a + bh + cH}{2}$$

Regular polygon

A = area; n = number of sides.

$x = 360° \div n$ $B = 180° - x$

$$A = \frac{nsr}{2} = \frac{ns}{2}\sqrt{R^2 - \frac{s^2}{4}}$$

$$R = \sqrt{r^2 + \frac{s^2}{4}} \qquad r = \sqrt{R^2 - \frac{s^2}{4}}$$

$s = 2\sqrt{R^2 - r^2}$

Circle

A = area; C = circumference.

$A = 0.7854\ d^2$

$C = 3.1416\ d$

$r = C \div 6.2832 = 0.564\ \sqrt{A}$

$d = C \div 3.1416 = 1.128\ \sqrt{A}$

Circular sector

A = area; l = length of arc; x = angle, in degrees.

$$l = \frac{2A}{r}$$

$A = \frac{1}{2} rl$

$$x = \frac{57.296\,l}{r} \qquad r = \frac{2A}{l}$$

Circular segment

A = area; l = length of arc; x = angle, in degrees.

$c = 2\sqrt{h(2r - h)}$

$A = \frac{1}{2}[rl - c(r - h)]$

$l = 0.01745\ rx$

$h = r - \frac{1}{2}\sqrt{4r^2 - c^2}$

$$x = \frac{57.296\,l}{r}$$

Ellipse

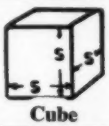
A = area;

P = perimeter or circumference.

$A = 3.1416\ ab$.

An approximate formula for the perimeter is:

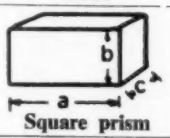
$P = 3.1416\sqrt{2(a^2 + b^2)}$



Cube

V = volume.

$V = s^3$



Square prism

V = volume.

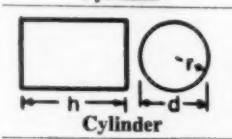
$V = abc$

$$a = \frac{V}{bc} \qquad b = \frac{V}{ac} \qquad c = \frac{V}{ab}$$

Pyramid

V = volume.

$V = \frac{1}{3}\ h \times$ area of base.



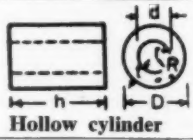
Cylinder

V = volume; S = area of curved surface.

$V = 0.7854\ d^2h$

$S = 6.2832\ rh$

Area of all surfaces is S plus twice the area of an end.

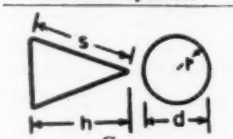


Hollow cylinder

V = volume.

$V = 0.7854\ h\ (D^2 - d^2)$

$= 3.1416\ ht\ (R + r)$



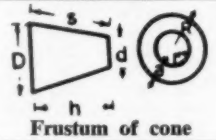
Cone

V = volume; A = area of conical surface.

$V = 0.2618\ d^2h$

$A = 1.5708\ ds$

$s = \sqrt{r^2 - h^2}$



Frustum of cone

V = volume; A = area of conical surface.

$V = 1.0472\ h\ (R^2 + Rr + r^2)$

$A = 3.1416\ s\ (R + r)$

$a = R - r \qquad s = \sqrt{a^2 + h^2}$

Sphere

V = volume; A = area of surface.

$V = 0.5236\ d^3$

$A = 3.1416\ d^2$

$r = 0.6204 \times$ cube root of V

Spherical segment

V = volume; A = area of spherical surface.

$$V = 3.1416\ h^2\left(r - \frac{h}{3}\right)$$

$A = 2\pi rh$

$c = 2\sqrt{h(2r - h)}$

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1/8 TO 20

Diam.	Circum.	Area	Diam.	Circum.	Area
1/8	.3927	.012272	10	31.416	78.54
1/4	.7854	.049087	10 1/8	31.8087	80.5158
3/8	1.1781	.110447	10 1/4	32.2014	82.5161
1/2	1.5708	.19635	10 3/8	32.5941	84.5409
5/8	1.9635	.306796	10 1/2	32.9868	86.5903
3/4	2.3562	.441787	10 5/8	33.3795	88.6643
7/8	2.7489	.601322	10 3/4	33.7722	90.7628
1	3.1416	.7854	10 7/8	34.1649	92.8858
1 1/8	3.5343	.99402	11	34.5576	95.0334
1 1/4	3.927	1.2272	11 1/8	34.9503	97.2055
1 3/8	4.3197	1.4849	11 1/4	35.343	99.4022
1 1/2	4.7124	1.7671	11 3/8	35.7357	101.6234
1 5/8	5.1051	2.0739	11 1/2	36.1284	103.8691
1 3/4	5.4978	2.4053	11 5/8	36.5211	106.1394
1 7/8	5.8905	2.7612	11 3/4	36.9138	108.4343
2	6.2832	3.1416	11 7/8	37.3065	110.7537
2 1/8	6.6759	3.5466	12	37.6992	113.098
2 1/4	7.0686	3.9761	12 1/8	38.0919	115.466
2 3/8	7.4613	4.4301	12 1/4	38.4846	117.859
2 1/2	7.854	4.9087	12 3/8	38.8773	120.277
2 5/8	8.2467	5.4119	12 1/2	39.27	122.719
2 3/4	8.6394	5.9396	12 5/8	39.6627	125.185
2 7/8	9.0321	6.4918	12 3/4	40.0554	127.677
3	9.4248	7.0686	12 7/8	40.4481	130.192
3 1/8	9.8175	7.6699	13	40.8408	132.733
3 1/4	10.2102	8.2958	13 1/8	41.2335	135.297
3 3/8	10.6029	8.9462	13 1/4	41.6262	137.887
3 1/2	10.9956	9.6211	13 3/8	42.0189	140.501
3 5/8	11.3883	10.3206	13 1/2	42.4116	143.139
3 3/4	11.781	11.0447	13 5/8	42.8043	145.802
3 7/8	12.1737	11.7933	13 3/4	43.197	148.49
4	12.5664	12.5664	13 7/8	43.5897	151.202
4 1/8	12.9591	13.3641	14	43.9824	153.938
4 1/4	13.3518	14.1863	14 1/8	44.3751	156.7
4 3/8	13.7445	15.033	14 1/4	44.7678	159.485
4 1/2	14.1372	15.9043	14 3/8	45.1605	162.296
4 5/8	14.5299	16.8002	14 1/2	45.5532	165.13
4 3/4	14.9226	17.7206	14 5/8	45.9459	167.99
4 7/8	15.3153	18.6655	14 3/4	46.3386	170.874
5	15.708	19.635	14 7/8	46.7313	173.782
5 1/8	16.1007	20.629	15	47.124	176.715
5 1/4	16.4934	21.6476	15 1/8	47.5167	179.673
5 3/8	16.8861	22.6907	15 1/4	47.9094	182.655
5 1/2	17.2788	23.7583	15 3/8	48.3021	185.661
5 5/8	17.6715	24.8505	15 1/2	48.6948	188.692
5 3/4	18.0642	25.9673	15 5/8	49.0875	191.748
5 7/8	18.4569	27.1086	15 3/4	49.4802	194.828
6	18.8496	28.2744	15 7/8	49.8729	197.933
6 1/8	19.2423	29.4648	16	50.2656	201.062
6 1/4	19.635	30.6797	16 1/8	50.6583	204.216
6 3/8	20.0277	31.9191	16 1/4	51.051	207.395
6 1/2	20.4204	33.1831	16 3/8	51.4437	210.598
6 5/8	20.8131	34.4717	16 1/2	51.8364	213.825
6 3/4	21.2058	35.7848	16 5/8	52.2291	217.077
6 7/8	21.5985	37.1224	16 3/4	52.6218	220.354
7	21.9912	38.4846	16 7/8	53.0145	223.655
7 1/8	22.3839	39.8713	17	53.4072	226.981
7 1/4	22.7766	41.2826	17 1/8	53.7999	230.331
7 3/8	23.1693	42.7184	17 1/4	54.1926	233.706
7 1/2	23.562	44.1787	17 3/8	54.5853	237.105
7 5/8	23.9547	45.6636	17 1/2	54.978	240.529
7 3/4	24.3474	47.1731	17 5/8	55.3707	243.977
7 7/8	24.7401	48.7071	17 3/4	55.7634	247.45
8	25.1328	50.2656	17 7/8	56.1561	250.948
8 1/8	25.5255	51.8487	18	56.5488	254.47
8 1/4	25.9182	53.4563	18 1/8	56.9415	258.016
8 3/8	26.3109	55.0884	18 1/4	57.3342	261.587
8 1/2	26.7036	56.7451	18 3/8	57.7269	265.183
8 5/8	27.0963	58.4264	18 1/2	58.1196	268.803
8 3/4	27.489	60.1322	18 5/8	58.5123	272.448
8 7/8	27.8817	61.8625	18 3/4	58.905	276.117
9	28.2744	63.6174	18 7/8	59.2977	279.811
9 1/8	28.6671	65.3968	19	59.6904	283.529
9 1/4	29.0598	67.2008	19 1/8	60.0831	287.272
9 3/8	29.4525	69.0293	19 1/4	60.4758	291.04
9 1/2	29.8452	70.8823	19 3/8	60.8685	294.832
9 5/8	30.2379	72.7599	19 1/2	61.2612	298.648
9 3/4	30.6306	74.6621	19 5/8	61.6539	302.489
9 7/8	31.0233	76.5888	19 3/4	62.0466	306.355
			19 7/8	62.4393	310.245
			20	62.832	314.16

STANDARD TWIST DRILL SIZES

Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.
1/2	0.5000	0.1963	3	0.213	0.03563	3/32	0.0938	0.00690
31/64	0.4844	0.1843	4	0.209	0.03431	42	0.0935	0.00687
15/32	0.4688	0.1726	5	0.2055	0.03317	43	0.0890	0.00622
29/64	0.4531	0.1613	6	0.204	0.03269	44	0.0860	0.00581
7/16	0.4375	0.1503	13/64	0.2031	0.03241	45	0.0820	0.00528
27/64	0.4219	0.1398	7	0.201	0.03173	46	0.0810	0.00515
Z	0.413	0.1340	8	0.199	0.03110	47	0.0785	0.00484
13/32	0.4063	0.1296	9	0.196	0.03017	5/64	0.0781	0.00479
Y	0.404	0.1282	10	0.1935	0.02940	48	0.0760	0.00454
X	0.397	0.1238	11	0.191	0.02865	49	0.0730	0.00419
25/64	0.3906	0.1198	12	0.189	0.02806	50	0.0700	0.00385
W	0.386	0.1170	3/16	0.1875	0.02761	51	0.0670	0.00353
V	0.377	0.1116	13	0.185	0.02688	52	0.0635	0.00317
3/8	0.375	0.1104	14	0.182	0.02602	1/16	0.0625	0.00307
U	0.368	0.1064	15	0.1800	0.02554	53	0.0595	0.00278
23/64	0.3594	0.1014	16	0.1770	0.02461	54	0.0550	0.00238
T	0.358	0.1006	17	0.1730	0.02351	55	0.0520	0.00212
S	0.348	0.09511	11/64	0.1719	0.02320	3/64	0.0473	0.00173
11/32	0.3438	0.09281	18	0.1695	0.02256	56	0.0465	0.001698
R	0.339	0.09026	19	0.1660	0.02164	57	0.0430	0.001452
Q	0.332	0.08657	20	0.1610	0.02036	58	0.0420	0.001385
21/64	0.3281	0.08456	21	0.1590	0.01986	59	0.0410	0.001320
P	0.323	0.08194	22	0.1570	0.01936	60	0.0400	0.001257
O	0.316	0.07843	5/32	0.1563	0.01917	61	0.039	0.001195
5/16	0.3125	0.07670	23	0.1540	0.01863	62	0.038	0.001134
N	0.302	0.07163	24	0.1520	0.01815	63	0.037	0.001075
19/64	0.2969	0.06922	25	0.1495	0.01755	64	0.036	0.001018
M	0.295	0.06835	26	0.1470	0.01697	65	0.035	0.000962
L	0.29	0.06605	27	0.1440	0.01629	66	0.033	0.000855
9/32	0.2813	0.06213	7/64	0.1406	0.01553	67	0.032	0.000804
K	0.281	0.06202	28	0.1405	0.01549	1/32	0.0313	0.000765
J	0.277	0.06026	29	0.1360	0.01453	68	0.031	0.000755
I	0.272	0.05811	30	0.1285	0.01296	69	0.0292	0.000670
H	0.266	0.05557	1/8	0.1250	0.01227	70	0.028	0.000616
17/64	0.2656	0.05542	31	0.1200	0.01131	71	0.026	0.000531
G	0.261	0.05350	32	0.1160	0.01057	72	0.025	0.000491
F	0.257	0.05187	33	0.1130	0.01003	73	0.024	0.000452
E1/4	0.2500	0.04909	34	0.1110	0.00968	74	0.0225	0.000398
D	0.246	0.04753	35	0.1100	0.00950	75	0.021	0.000346
C	0.242	0.04600	7/64	0.1094	0.00940	76	0.020	0.000314
B	0.238	0.04449	36	0.1065	0.00891	77	0.108	0.000254
15/64	0.2344	0.04314	37	0.1040	0.00849	78	0.016	0.000201
A	0.234	0.04301	38	0.1015	0.00809	1/64	0.0156	0.000191
1	0.228	0.04083	39	0.0995	0.00778	79	0.0145	0.000165
2	0.221	0.03836	40	0.0980	0.00754	80	0.0135	0.000143
7/32	0.2188	0.03758	41	0.0960	0.00724			

NOTE—Designations are in fractions of an inch, in standard twist drill letters, or in standard twist drill numbers, the latter being the same as steel wire gauge numbers. *(Courtesy of AGA.)*

GAGE THICKNESS WEIGHT STEEL SHEETS

Gage	Thickness, inches	Steel	Galvanized Steel	Gage	Thickness, inches	Steel	Galvanized Steel
		weight, pounds per square foot				weight, pounds per square foot	
7	.1793	7.500	——	19	.0418	1.750	1.9062
8	.1644	6.875	——	20	.0359	1.500	1.6562
9	.1494	6.250	——	21	.0329	1.375	1.5312
10	.1345	5.625	5.7812	22	.0299	1.250	1.4062
11	.1196	5.000	5.1562	23	.0269	1.125	1.2812
12	.1046	4.375	4.5312	24	.0239	1.000	1.1562
13	.0897	3.750	3.9062	25	.0209	.875	1.0312
14	.0747	3.125	3.2812	26	.0179	.750	.9062
15	.0673	2.812	2.9687	27	.0164	.6875	.8437
16	.0598	2.500	2.6562	28	.0149	.625	.7812
17	.0538	2.250	2.4062	29	.0135	.5625	.7187
18	.0478	2.000	2.1562	30	.0120	.500	.6562

Deviation of Gases from Ideal Gas Laws

Storage cylinders, operating at relatively high pressures, are capable of offering increased storage capacity, considering the effect of deviation from the ideal gas law, to the extent of approximately 40 per cent over underground storage sands.

In the case of mixtures of gases, such as natural gas, deviation from the ideal gas law is dependent on the composition of the mixture. A method of determining this deviation for a gas of any composition and of calculating the increase in volumetric capacity under optimum operating conditions is presented.

In the compression of a gas, when working pressure exceeds approximately 50 psi gage, there is a difference between the actual volume and the volume expected as determined by the ideal gas law,

$$PV = NR'T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where

P = pressure in pounds per square inch absolute

V = volume in cubic feet

N = number of pound-moles of gas = $\frac{\text{Weight of gas in pounds}}{\text{molecular weight}}$

R' = universal gas constant = 10.71 for cubic foot and pounds per square inch

T = temperature, absolute = 460 + °F

The difference is generally a shrinkage accompanied by a corresponding increase in density. This shrinkage, or deviation, is a function of both pressure and temperature, and reaches a maximum at the critical pressure and temperature of the gas.

Since the ideal gas law (Equation 1) has been used in the deviation of nearly all equations of state, the most convenient method for determining the pressure, volume, temperature relationships of a gas or gaseous mixture is to introduce into Equation 1 a compressibility factor Z which represents the deviation of the gas in question from the ideal gas laws and may be expressed as follows:

TABLE 1, Properties of Gases

Gas	Formula	Molecular wt.	Boiling point at atmosphere °F	Specific gravity Air = 1.00	Critical temperature °F abs.	Critical pressure psi abs.
Methane	CH_4	16.03	—259	0.553	344	673
Ethane	C_2H_6	30.05	—127	1.037	549	712
Propane	C_3H_8	44.06	— 44	1.521	666	632
Isobutane	C_4H_{10}	58.08	10	2.005	732	544
Isopentane	C_5H_{12}	72.09	82	2.488	829	1482
Carbon dioxide	CO_2	44.00	—109	1.520	548	1073
Nitrogen	N_2	28.02	—320	0.970	227	492
Oxygen	O_2	32.00	—297	1.105	278	730

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$$PV = ZNR'T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

Z = compressibility factor

Actually, the compressibility factor Z is a dimensionless correction factor dependent on the character of the gas, the temperature, and the pressure. Values of Z have been experimentally determined[1,2*], and were found to be a function of reduced temperature, and have been plotted accordingly in Fig. 1.

The compressibility factor Z, or the deviation of a gas or a gas mixture from the ideal gas laws, is expressed in terms of reduced pressure P_r (ratio of the actual absolute pressure to the critical pressure) and of reduced temperature T_r (ratio of the actual temperature to the critical temperature), the relationship being expressed as follows:

$$P_r = P/P_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$T_r = T/T_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

P = pressure in pounds per square inch absolute

T = temperature, absolute = 460 + °F

P_c = critical pressure of gas or gas mixture

T_c = critical temperature of gas or gas mixture

The critical pressure of a gas is the pressure under which the gas may exist in a gaseous state in equilibrium with its liquid at the critical temperature. The critical temperature is the temperature above which a gas cannot be liquefied by pressure alone. Values of critical constants may be obtained from critical tables and handbooks, or reference may be made to Table 1 wherein are listed properties of constituent gases.

In a gaseous mixture consisting of numerous component gases, the compressibility factor is determined by having recourse to the so-called pseudo-critical values of the mixture. The pseudo-critical pressure is the molecular average critical pressure of the gas mixture and the pseudo-critical temperature is the molecular average critical temperature of the mixture. The relationship to the critical pressure and temperature of the fundamental gases may be expressed as follows:

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where:

N_a = Gas (a) of gas mixture as a volume fraction

N_b = Gas (b) of gas mixture as a volume fraction

P_c = Pseudo-critical pressure of gas mixture

$(P_c)_a$ = Critical pressure of N_a

$(P_c)_b$ = Critical pressure of N_b

T_c = Pseudo-critical temperature of gas mixture

$(T_c)_a$ = Critical temperature of N_a

$(T_c)_b$ = Critical temperature of N_b

TABLE 2. Various Gas Analyses.

Component	Formula	Example	Natural gas		Coke-oven gas	Producer gas: Pittsburgh coal Best	Producer gas: Pittsburgh coal Average	Producer gas: Illinois coal
Analysis number			1	2	3	4	5	6
Methane	CH_4	84.8	84.5	94.5	29.7	3.4	2.3	2.5
Ethane	C_2H_6	14.3	11.5	0.5	1.1	....	....	....
Carbon monoxide	CO	....	....	....	5.9	27.5	24.7	25.4
Hydrogen	H_2	....	....	....	57.0	12.7	15.0	11.0
Oxygen	O_2	0.2	....	0.3	....	0.2	0.2	0.1
Nitrogen	N_2	0.6	3.8	4.0	0.7	50.8	52.2	54.0
Carbon dioxide	CO_2	0.2	0.2	0.2	0.7	4.6	4.8	5.2
Ethylene	C_2H_4	....	....	0.5	3.4	0.8	0.8	0.6
Critical pressure psi abs	Pc	678.1	672.0	667.3	381.6	494.8	486.4	494.8
Critical temperature, °F abs	Tc	372.6	363.7	341.4	179.5	231.0	226.1	231.1
Reduced temperature	Tr	1.40	1.43	1.52	2.90	2.25	2.30	2.25

TABLE 3. Determination of compressibility factor and atmospheric volumetric multiplier.

Given: Critical Pressure = 678.1 psi abs.
Critical Temperature = 372.6° F abs.
Reduced Temperature = 1.396

Storage pressure Pp	Reduced pressure $Pr = \frac{Pp}{678.1}$	From Fig. 1 Zp For Tr = 1.396 For $Pr = \frac{Pp}{678.1}$	14.73Zp	Atmospheric volumetric multiplier $\frac{Pp}{14.73Zp}$
100	.147	.983	14.48	6.91
250	.369	.955	14.07	17.77
500	.737	.912	13.43	37.23
750	1.106	.871	12.83	58.46
1000	1.475	.828	12.20	81.97
1250	1.843	.790	11.64	107.39
1500	2.212	.756	11.14	134.65
1750	2.581	.736	10.84	161.44
2000	2.949	.721	10.62	188.32
2250	3.318	.718	10.58	212.67
2500	3.687	.722	10.64	234.96
2750	4.055	.733	10.80	254.63
3000	4.424	.748	11.02	272.23

In order to illustrate the determination of the compressibility factor, the following example is cited:

Example — Gas analysis, per cent by volume: Methane, 84.81; Ethane, 14.26; Nitrogen, 0.63; Carbon Dioxide, 0.15; Oxygen, 0.15. Required, the deviation for 2000 psi absolute and 60° F. The pseudo-critical pressure and temperature must be determined by means of Equations (5) and (6) and Table 1.

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \ldots \quad (5)$$

$$P_c = 673(0.8481) + 712(0.1426) + 492(0.0063) + 1073(0.0015) + 730(0.0015) = 678.1 \text{ psi absolute}$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \ldots \quad (6)$$

$$T_c = 344(0.8481) + 549(0.1426) + 227(0.0063) + 548(0.0015) + 278(0.0015) = 372.6° \text{ F absolute}$$

$$P_r = P/P_c \quad (3)$$

$$P_r = \frac{2000}{678.1} = 2.949$$

$$T_r = T/T_c \quad (4)$$

$$T_r = \frac{60 + 460}{372.6} = 1.396$$

Reduced pressure and reduced temperature are determined from Equations (3) and (4).

From Fig. 1, for $T_r = 1.395$ and $P_r = 2.949$, we find the compressibility factor $Z = 0.722$. It should be noted that if in the preceding example the gas had been at atmospheric pressure, the compressibility factor would approximate unity.

For comparative purposes Fig. 2 has been prepared based on the seven gas analyses of Table 2 giving the compressibility factor Z as a function of storage pressure and reduced temperature. Similarly, for any other gas analyses plots could be made to indicate the optimum pressure-deviation relationship. In this manner the designer of storage cylinders will be able to determine the magnitude of the increase in the storage capacity under optimum conditions. In the case of gas analysis No. 1, the best operating pressure would be 2250 psi absolute, the compressibility factor being .740.

If under standard conditions of pressure and temperature the volumetric content of a cylinder is known, the magnitude of the increase in storage capacity may be predicted based on the deviation from the ideal gas laws and the storage pressure.

$$P_a V_a = Z_a NR'T \text{ and } P_p V_p = Z_p NR'T$$

where subscripts a and p represent values at standard or atmospheric conditions and under pressure, then

$$V_a = \frac{Z_a P_p}{Z_p P_a} V_p \quad (7)$$

but Z_a = unity at standard conditions and $P_a = 14.73$ psi. When substituted in Equation (7) the expression in terms of standard volume will be

$$V_a = \frac{P_p}{14.73 Z_p} V_p \quad (8)$$

Therefore, the expression $\frac{P_p}{14.73 Z_p}$ represents a volumetric multiplier and, knowing the volume under standard conditions, the volume of gas that can be stored under operating conditions may be anticipated by multiplying the known volume by this calculated value.

Atmospheric volumetric multipliers for the seven gas analyses of Table 2 have been determined and are shown in Fig. 3, and, similarly, for any other gas analysis a plot may be established to show the expected volumetric increase for each analysis.

To further illustrate, using the gas analysis of the previous example, Table 3 shows the required calculations for the determination of the compressibility factor Z and the volumetric multiplier k for a storage pressure range of 100 psi to 3000 psi absolute.

In the foregoing discussion the probabilities of hydrate formation or liquefaction of the gas have not been taken into consideration. For any specific gas mixture these critical points should be determined for the anticipated operation conditions before proceeding with the investigation of optimum conditions of storage.

Bibliography

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2. Chemical Engineers' Handbook. By John H. Perry, McGraw-Hill Book Company, New York.

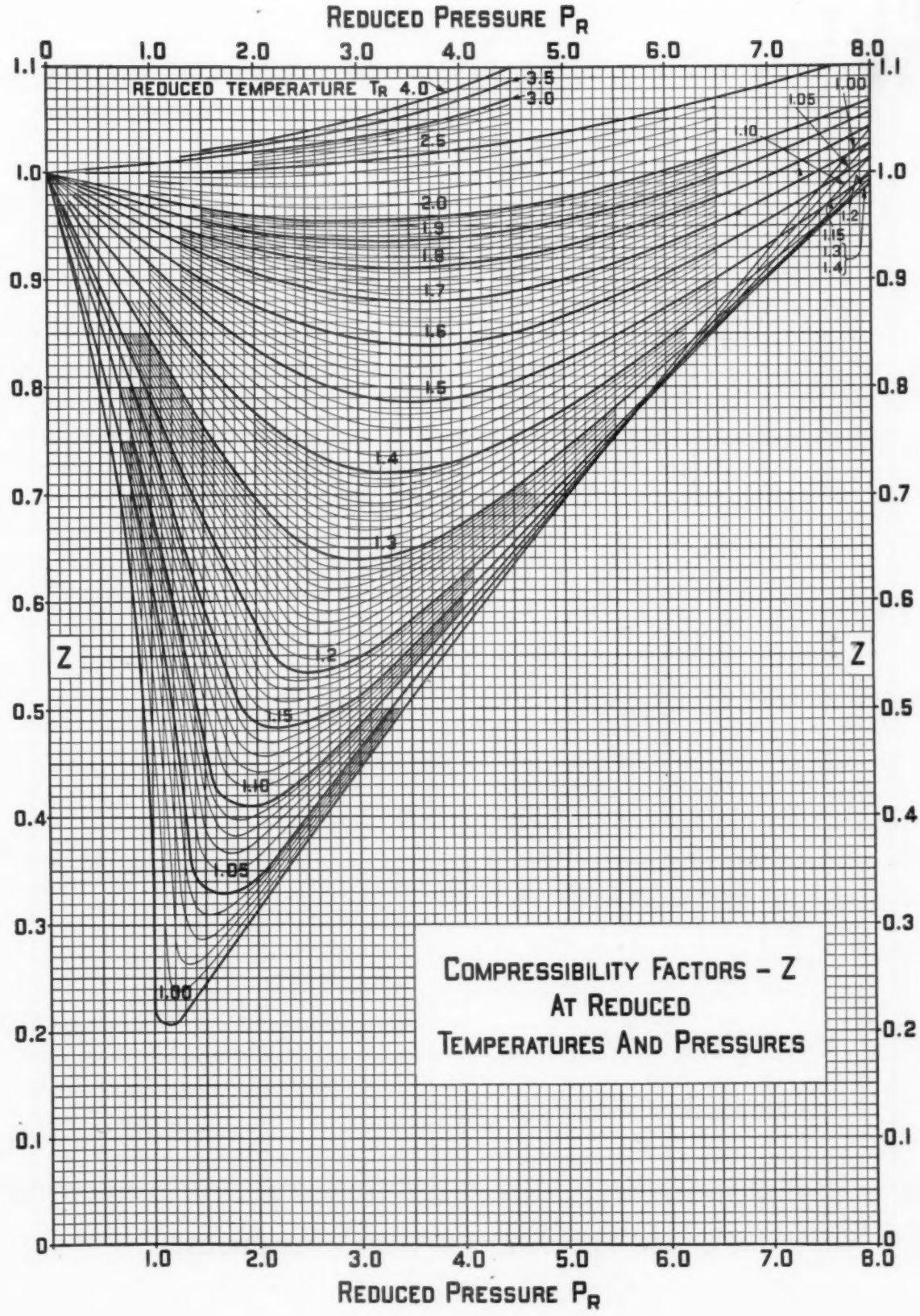

FIG. 1.

By permission, from "Natural Gasoline and the Volatile Hydrocarbons," by Brown, Katz, Oberfell and Alden.

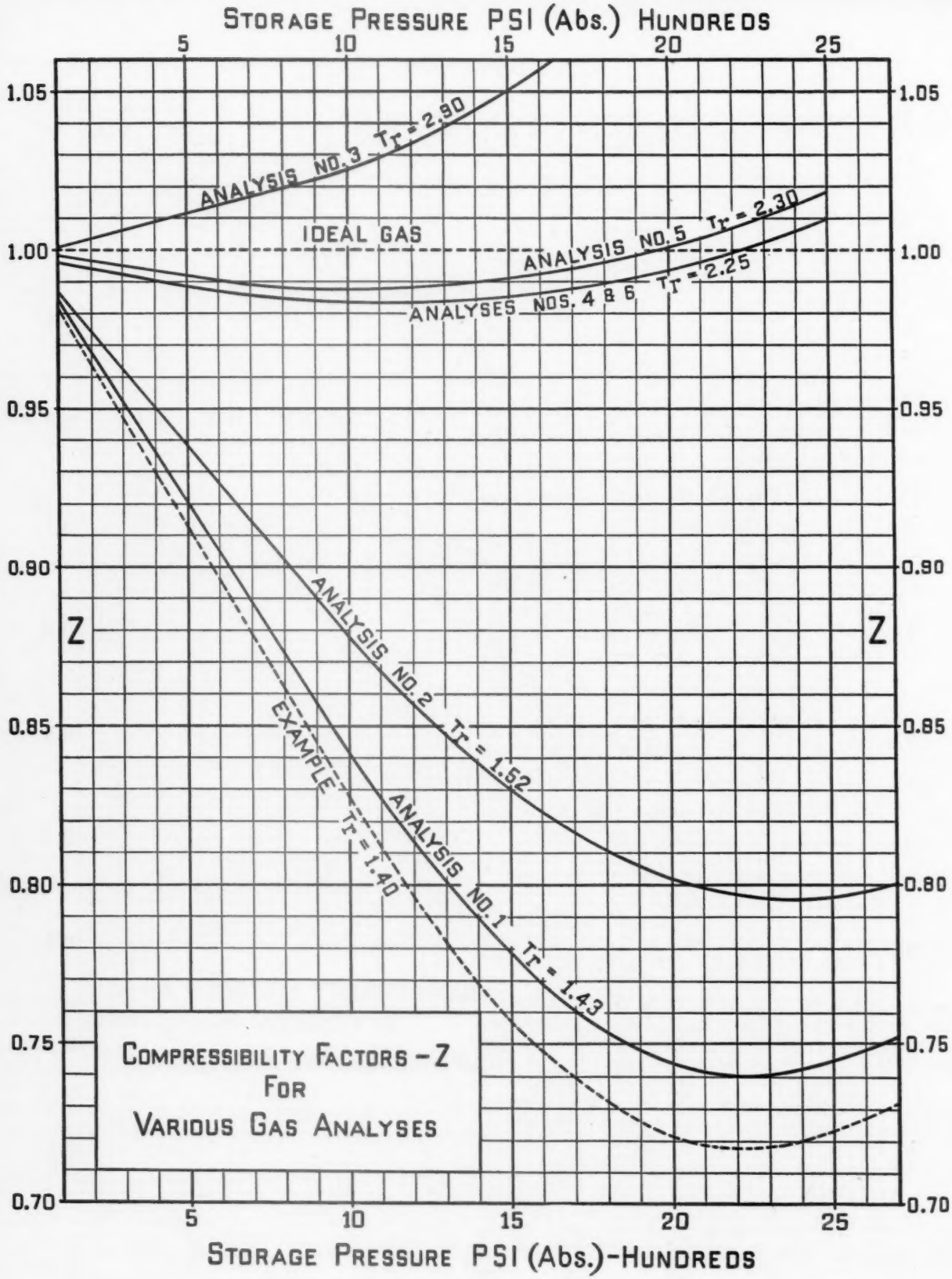
STORAGE PRESSURE PSI (Abs.) HUNDREDS
5
10
15
20
25
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Z
ANALYSIS NO. 3 Tr = 2.90
IDEAL GAS
ANALYSIS NO. 5 Tr = 2.30
ANALYSES NOS. 4 & 6 Tr = 2.25
ANALYSIS NO. 2 Tr = 1.52
EXAMPLE Tr = 1.40
ANALYSIS NO. 1 Tr = 1.43
COMPRESSIBILITY FACTORS - Z
FOR
VARIOUS GAS ANALYSES
STORAGE PRESSURE PSI (Abs.)-HUNDREDS

FIG. 2.

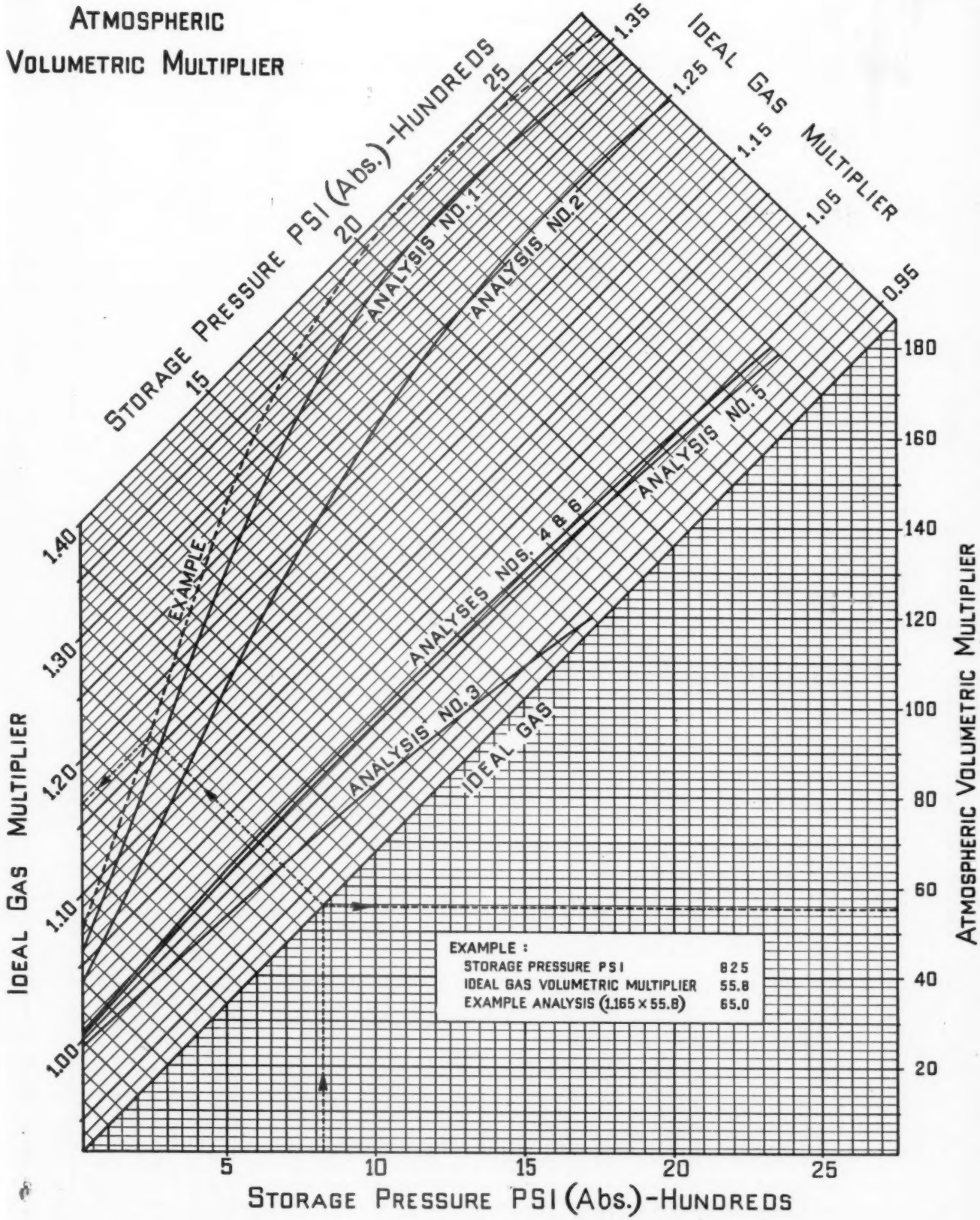
ATMOSPHERIC
VOLUMETRIC MULTIPLIER
STORAGE PRESSURE PSI (Abs.)-HUNDREDS
IDEAL GAS MULTIPLIER
1.35
1.25
1.15
1.05
0.95
25
20
15
ANALYSIS NO. 1
ANALYSIS NO. 2
ANALYSIS NO. 5
ANALYSES NOS. 4 & 6
ANALYSIS NO. 3
IDEAL GAS
EXAMPLE
1.40
1.30
1.20
1.10
1.00
180
160
140
120
100
80
60
40
20
IDEAL GAS MULTIPLIER
ATMOSPHERIC VOLUMETRIC MULTIPLIER
EXAMPLE :
STORAGE PRESSURE PSI 825
IDEAL GAS VOLUMETRIC MULTIPLIER 55.8
EXAMPLE ANALYSIS (1.165 × 55.8) 65.0
5
10
15
20
25
STORAGE PRESSURE PSI (Abs.)-HUNDREDS

FIG. 3.

VAPOR PRESSURES, POUNDS PER SQUARE INCH ABSOLUTE

Temperature, °F	Acetylene, C_2H_2	Ammonia, NH_3	Benzene, C_6H_6	n-Butane, C_4H_{10}	Isobutane, C_4H_{10}	Carbon Dioxide, CO_2	Carbon Disulfide, CS_2	Ethane, C_2H_6	Ethyl Alcohol, C_2H_5OH	Ethyl Chloride C_2H_5Cl	Hydrogen Sulfide, H_2S	Methyl Chloride, CH_3Cl	Naphthalene, $C_{10}H_8$		Propane, C_3H_8	Sulfur dioxide, SO_2	Toluene, C_7H_8	Water, H_2O	*m*-Xylene, C_8H_{10}
													Dry	Moist					
—20	162	18.30	....	....	7.50	215.02	0.53	158	0.022	2.16	57.5	11.75	....	....	25.4	5.883	....	....	....
—10	196	23.74	....	....	9.28	257.46	0.74	185	0.036	2.94	70.0	15.0	....	....	31.4	7.863	....	....	....
0	232	30.42	....	7.3	12.1	305.5	1.00	218	0.058	3.93	84.0	18.8	....	....	38.2	10.35	....	....	....
10	271	38.51	....	9.3	14.8	360.2	1.36	250	0.090	5.13	100	23.3	....	....	46.5	13.42	....	....	....
20	319	48.21	....	11.8	18.2	421.8	1.80	290	0.140	6.65	120	28.8	....	....	55.5	17.18	....	....	....
30	372	59.74	0.48	14.4	23.3	490.8	2.30	334	0.220	8.40	143	35.2	0.000096	0.000029	66.3	21.70	0.125	....	0.031
32	387	62.29	0.52	15.8	23.2	505.5	2.46	346	0.236	8.85	150	36.6	0.00011	0.000033	68.0	22.47	0.137	0.0887	0.034
40	430	73.32	0.66	18.4	26.9	567.8	2.96	381	0.330	10.53	169	42.6	0.00018	0.000057	78.0	27.10	0.176	0.1217	0.042
50	495	89.19	0.88	22.7	32.2	653.6	3.83	418	0.456	13.20	197	51.5	0.00034	0.00012	91.8	33.45	0.247	0.1780	0.061
60	565	107.6	1.14	27.1	38.7	748.6	4.75	496	0.640	16.5	230	61.6	0.00060	0.00026	107.1	40.93	0.335	0.2561	0.093
70	645	128.8	1.51	32.7	45.8	853.4	5.93	560	0.910	20.0	267	73.3	0.0011	0.00057	124.0	49.62	0.455	0.3628	0.131
80	735	153.0	1.95	39.0	53.9	968.7	7.30	632	1.25	24.3	302	85.3	0.0013	0.0013	142.8	59.68	0.607	0.5067	0.178
90	830	180.6	2.51	46.2	63.3	....	9.00	708	1.71	29.0	344	102.1	0.0032	0.0029	164.0	71.25	0.790	0.6980	0.241
100	..	211.9	3.20	55.0	74.7	....	10.8	...	2.32	34.9	392	118.8	0.0054	0.0054	187.0	84.52	1.03	0.9487	0.330
110	...	247.0	4.05	64.2	85.1	....	13.3	...	3.09	41.1	442	137.6	0.0088	0.0094	212.0	99.76	1.32	1.274	0.435
120	...	286.4	4.22	75	98.0	....	16.0	...	4.02	48.1	500	158.8	0.0142	0.016	240.0	120.9	1.70	1.692	0.570
130	...	329	6.41	87	112.0	....	19.0	...	5.27	56.3	560	173	0.0218	....	272	135.0	2.13	2.221	0.745
140	...	379	7.53	101	126.8	....	22.6	...	6.82	66.1	632	200	0.0322	....	....	157.8	2.70	2.887	0.978
150	...	435	9.2	115	....	....	26.5	...	8.65	76.0	700	223	0.0439	....	....	181	2.30	3.716	1.22
160	...	495	11.0	132	....	....	30.9	...	10.9	86.3	778	253	0.071	....	....	209	4.03	4.739	1.53
170	...	560	13.0	151	....	....	35.9	...	13.5	99.0	862	287	0.105	....	....	239	5.00	5.990	1.94
180	...	640	15.4	172	....	....	41.9	...	17.0	113	962	322	0.155	....	....	272	6.02	7.510	2.42
190	...	715	18.2	194	....	....	48.0	...	21.0	127	1050	360	0.217	....	....	309	7.3	9.336	2.98
200	...	800	21.7	219	....	....	55.2	...	25.5	142	1160	400	0.277	....	..	350	8.7	11.525	3.62
210	...	890	25.4	248	....	....	63.0	...	31.1	161	1280	445	0.347	....	....	399	10.3	14.123	4.42
220	...	990	....	....	....	....	71.5	..	37.8	180	....	495	0.419	....	....	449	....	17.188	5.30
230	...	1100	....	....	....	....	81.6	...	45.7	203	....	550	0.547	....	....	501	....	20.78	6.35
240	...	1210	....	....	....	....	91.8	...	54.5	230	....	605	0.68	....	....	561	....	24.97	7.55
250	...	1340	....	....	....	....	103	...	64.5	260	....	670	0.85	....	....	624	....	29.82	9.0
	d	d, h	b, d	b, e, f	c, f	d, e, f	d	d	d	d, f,	d	d, e	b, d,	b	c, f	d, f	a, d	g	d

[a] Gas Chemists Handbook, Third Edition, 1929.

[b] Gas Engineers' Handbook, First Edition, 1934.

[c] Handbook of Butane-Propane Gases, Second Edition, 1935.

[d] Handbook of Chemistry and Physics, Nineteenth Edition, 1934.

[e] *Heating and Ventilating*, September and October 1938.

[f] L. S. Marks, Mechanical Engineers' Handbook, Third Edition, 1930.

[g] J. H. Keenan, "Steam Tables and Mollier Diagram," 1930.

[h] U. S. Bur. of Standards, Circular No. 142, 1923.

Note: Over small temperature intervals the logarithm of the vapor pressure plotted against temperature is practically a straight line. For longer temperature intervals the plot against reciprocal of the absolute temperature should be used.

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WATER VAPOR IN SATURATED GAS

Per cent by volume, calculated from the gas laws

Temperature, °F.	Pressure, Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	0.244	0.122	0.081	0.061	0.049	0.041	0.035	0.030	0.024	0.020	0.017
50	0.356	0.178	0.119	0.089	0.071	0.059	0.051	0.055	0.036	0.030	0.025
60	0.512	0.256	0.171	0.128	0.102	0.085	0.073	0.064	0.051	0.043	0.037
70	0.726	0.363	0.242	0.181	0.145	0.121	0.104	0.091	0.073	0.061	0.052
80	1.014	0.507	0.338	0.253	0.203	0.169	0.145	0.127	0.101	0.084	0.072
90	1.396	0.698	0.465	0.349	0.279	0.233	0.199	0.174	0.140	0.116	0.100
100	1.898	0.949	0.633	0.474	0.380	0.316	0.271	0.237	0.190	0.158	0.136

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

GALLONS OF WATER PER MILLION CUBIC FEET OF GAS

Pressure and temperature bases: 14.4 pounds per square inch and 60° F
Gas saturated with water vapor at indicated pressures and temperatures

Temperature, °F.	Pressure, Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	13.6	6.8	4.5	3.4	2.7	2.3	2.0	1.7	1.4	1.1	1.0
50	19.9	10.0	6.6	5.0	4.0	3.3	2.8	2.5	2.0	1.7	1.4
60	28.6	14.3	9.5	7.2	5.7	4.8	4.1	3.6	2.9	2.4	2.0
70	40.5	20.2	13.5	10.1	8.1	6.8	5.8	5.1	4.0	3.4	2.9
80	56.4	28.2	18.8	14.1	11.3	9.4	8.1	7.0	5.6	4.7	4.0
90	78.0	39.0	26.0	19.5	15.6	13.0	11.1	9.7	7.8	6.5	5.6
100	106.2	53.1	35.4	26.5	21.2	17.7	15.2	13.3	10.6	8.9	7.6

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VAPOR PRESSURE OF WATER

°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute
32	0.1803	0.08854	57	0.4686	0.2302	82	1.1016	0.5410	107	2.3786	1.1683
33	0.1878	0.09223	58	0.4858	0.2386	83	1.1378	0.5588	108	2.4491	1.2029
34	0.1955	0.09603	59	0.5035	0.2473	84	1.1750	0.5771	109	2.5214	1.2384
35	0.2035	0.09995	60	0.5218	0.2563	85	1.2133	0.5959	110	2.5955	1.2748
36	0.2118	0.10401	61	0.5407	0.2655	86	1.2527	0.6152	115	2.9948	1.4709
37	0.2203	0.10821	62	0.5601	0.2751	87	1.2931	0.6351	120	3.4458	1.6924
38	0.2292	0.11256	63	0.5802	0.2850	88	1.3347	0.6556	125	3.9539	1.9420
39	0.2383	0.11705	64	0.6009	0.2951	89	1.3775	0.6766	130	4.5251	2.2225
40	0.2478	0.12170	65	0.6222	0.3056	90	1.4215	0.6982	135	5.1653	2.5370
41	0.2576	0.12652	66	0.6442	0.3164	91	1.4667	0.7204	140	5.8812	2.8886
42	0.2677	0.13150	67	0.6669	0.3276	92	1.5131	0.7432	145	6.680	3.281
43	0.2782	0.13665	68	0.6903	0.3390	93	1.5608	0.7666	150	7.569	3.718
44	0.2891	0.14199	69	0.7144	0.3509	94	1.6097	0.7960	155	8.557	4.203
45	0.3004	0.14752	70	0.7392	0.3631	95	1.6600	0.8153	160	9.652	4.741
46	0.3120	0.15323	71	0.7648	0.3756	96	1.7117	0.8407	165	10.863	5.335
47	0.3240	0.15914	72	0.7912	0.3886	97	1.7647	0.8668	170	12.199	5.992
48	0.3364	0.16525	73	0.8183	0.4019	98	1.8192	0.8935	175	13.671	6.715
49	0.3493	0.17157	74	0.8462	0.4156	99	1.8751	0.9210	180	15.291	7.510
50	0.3626	0.17811	75	0.8750	0.4298	100	1.9325	0.9492	185	17.068	8.383
51	0.3764	0.18486	76	0.9046	0.4443	101	1.9915	0.9781	190	19.014	9.339
52	0.3906	0.19182	77	0.9352	0.4593	102	2.0519	1.0078	195	21.144	10.385
53	0.4052	0.19900	78	0.9666	0.4747	103	2.1138	1.0382	200	23.467	11.526
54	0.4203	0.20642	79	0.9989	0.4906	104	2.1775	1.0695	205	26.003	12.772
55	0.4359	0.2141	80	1.0321	0.5069	105	2.2429	1.1016	210	28.755	14.123
56	0.4520	0.2220	81	1.0664	0.5237	106	2.3099	1.1345	212	29.922	14.696

A special case of partial pressure is that due to vapor pressures of substances at or near their condensing conditions, especially when in the presence of some liquids. The kinetic theory has shown how separation of molecules will permit the evaporation of other gaseous molecules into the same space. All liquids exposed to an available space will partially change to vapor. The partial pressure of this vapor in the space above the liquid is given the name "vapor pressure." For each temperature of the liquid, there is a corresponding vapor pressure. When the vapor pressure equals the external pressure, the liquid is at its boiling point. For water under pressure of one atmosphere, 212° F is the temperature at which this phenomenon takes place.

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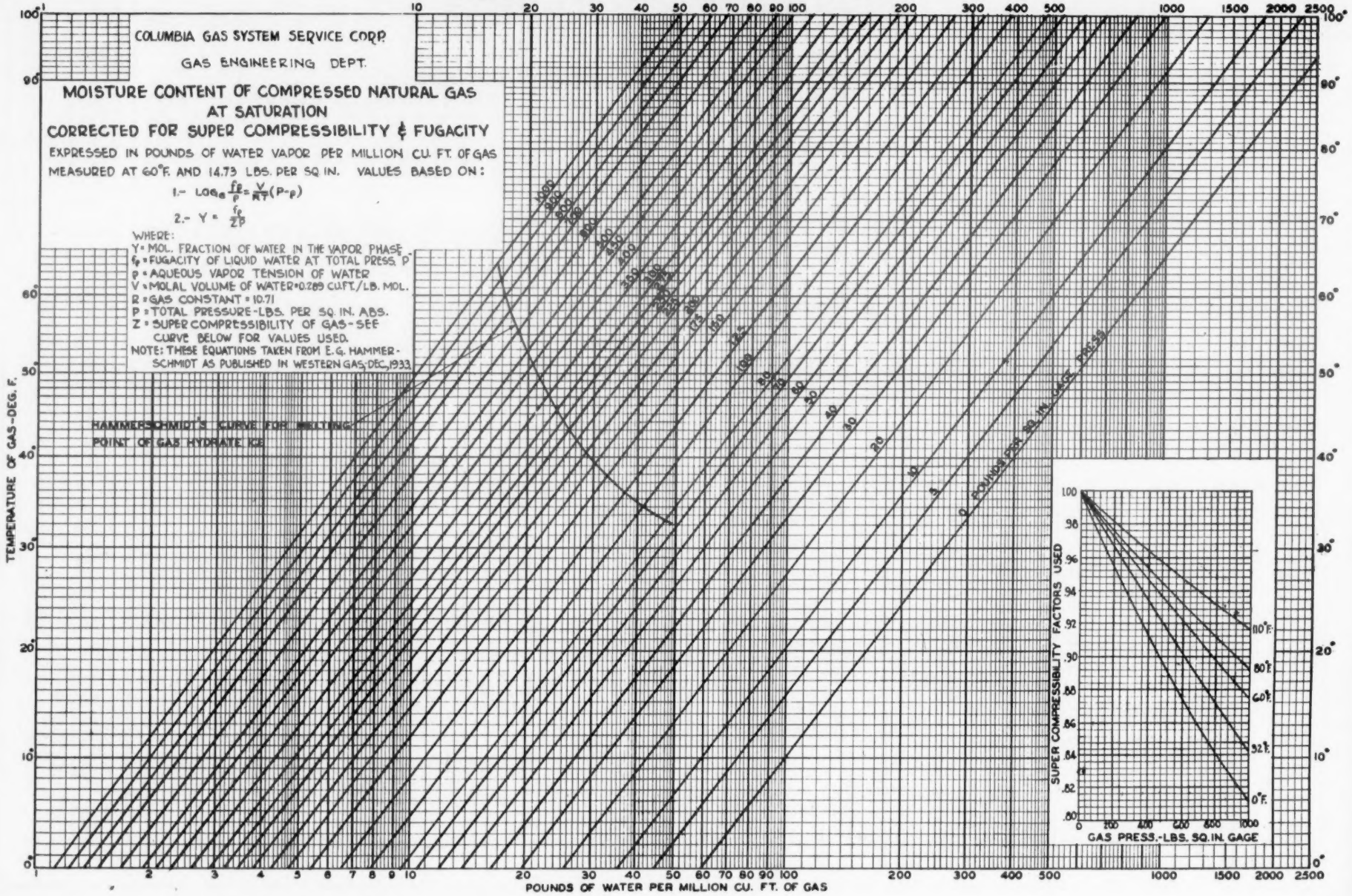
MOISTURE CONTENT OF COMPRESSED NATURAL GAS

CORRECTED FOR SUPERCOMPRESSIBILITY AND FUGACITY


COLUMBIA GAS SYSTEM SERVICE CORP.
GAS ENGINEERING DEPT.
MOISTURE CONTENT OF COMPRESSED NATURAL GAS
AT SATURATION
CORRECTED FOR SUPER COMPRESSIBILITY & FUGACITY
EXPRESSED IN POUNDS OF WATER VAPOR PER MILLION CU. FT. OF GAS MEASURED AT 60°F. AND 14.73 LBS. PER SQ. IN. VALUES BASED ON:
1.- $\log_e \frac{f_e}{p} = \frac{V}{RT}(P-p)$
2.- $Y = \frac{f_e}{ZP}$
WHERE:
Y = MOL. FRACTION OF WATER IN THE VAPOR PHASE
f_e = FUGACITY OF LIQUID WATER AT TOTAL PRESS. 'P'
p = AQUEOUS VAPOR TENSION OF WATER
V = MOLAL VOLUME OF WATER = 0.289 CU.FT./LB. MOL.
R = GAS CONSTANT = 10.71
P = TOTAL PRESSURE-LBS. PER SQ. IN. ABS.
Z = SUPER COMPRESSIBILITY OF GAS - SEE CURVE BELOW FOR VALUES USED.
NOTE: THESE EQUATIONS TAKEN FROM E.G. HAMMERSCHMIDT AS PUBLISHED IN WESTERN GAS, DEC., 1933.
HAMMERSCHMIDT'S CURVE FOR MELTING POINT OF GAS HYDRATE ICE
TEMPERATURE OF GAS - DEG. F.
POUNDS OF WATER PER MILLION CU. FT. OF GAS
POUNDS PER SQ. IN. GAGE PRESS.
SUPER COMPRESSIBILITY FACTORS USED
GAS PRESS.-LBS. SQ. IN. GAGE
110°F.
80°F.
60°F.
32°F.
0°F.

N.G.A.A. VOLUME CORRECTION FACTORS (1942)

SPECIFIC GRAVITIES AT 60° F./60° F.

Observed Temperature Degrees Fahrenheit	0.500	Propane 0.5079	0.510	0.520	0.530	0.540	0.550	0.560	iso-Butane 0.5631	0.570	0.580	n-Butane 0.5844	0.590	0.600	0.610	0.620	iso-Pentane 0.6246	0.630	n-Pentane 0.6310	0.640	0.650	0.660	0.670	0.680	0.690	0.700
	VOLUME CORRECTION FACTORS																									
−50	1.160	1.155	1.153	1.146	1.140	1.133	1.127	1.122	1.120	1.116	1.111	1.108	1.106	1.102												
−45	1.153	1.148	1.146	1.140	1.134	1.128	1.122	1.117	1.115	1.111	1.106	1.103	1.101	1.097												
−40	1.147	1.142	1.140	1.134	1.128	1.122	1.117	1.111	1.110	1.106	1.101	1.099	1.097	1.093												
−35	1.140	1.135	1.134	1.128	1.122	1.116	1.112	1.106	1.105	1.101	1.096	1.094	1.092	1.088												
−30	1.134	1.129	1.128	1.122	1.116	1.111	1.106	1.101	1.100	1.096	1.092	1.090	1.088	1.084												
−25	1.127	1.122	1.121	1.115	1.110	1.105	1.100	1.095	1.094	1.091	1.087	1.085	1.083	1.080												
−20	1.120	1.115	1.114	1.109	1.104	1.099	1.095	1.090	1.089	1.086	1.082	1.080	1.079	1.076												
−15	1.112	1.109	1.107	1.102	1.097	1.093	1.089	1.084	1.083	1.080	1.077	1.075	1.074	1.071												
−10	1.105	1.102	1.100	1.095	1.091	1.087	1.083	1.079	1.078	1.075	1.072	1.071	1.069	1.066												
− 5	1.098	1.094	1.094	1.089	1.085	1.081	1.077	1.074	1.073	1.070	1.067	1.066	1.065	1.062												
0	1.092	1.088	1.088	1.084	1.080	1.076	1.073	1.069	1.068	1.066	1.063	1.062	1.061	1.058	1.055	1.053	1.052	1.051	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.042
2	1.089	1.086	1.085	1.081	1.077	1.074	1.070	1.067	1.066	1.064	1.061	1.060	1.059	1.056	1.053	1.051	1.050	1.049	1.049	1.048	1.046	1.045	1.044	1.043	1.042	1.041
4	1.086	1.083	1.082	1.079	1.075	1.071	1.068	1.065	1.064	1.062	1.059	1.058	1.057	1.054	1.051	1.049	1.049	1.048	1.048	1.047	1.045	1.043	1.042	1.041	1.041	1.039
6	1.084	1.080	1.080	1.076	1.072	1.069	1.065	1.062	1.061	1.059	1.057	1.055	1.054	1.052	1.050	1.048	1.047	1.046	1.046	1.045	1.043	1.042	1.041	1.040	1.039	1.038
8	1.081	1.078	1.077	1.074	1.070	1.066	1.063	1.060	1.059	1.057	1.055	1.053	1.052	1.050	1.048	1.046	1.045	1.045	1.045	1.044	1.042	1.040	1.039	1.038	1.037	1.036
10	1.078	1.075	1.074	1.071	1.067	1.064	1.061	1.058	1.057	1.055	1.053	1.051	1.050	1.048	1.046	1.044	1.044	1.043	1.043	1.042	1.040	1.039	1.038	1.037	1.036	1.035
12	1.075	1.072	1.071	1.068	1.064	1.061	1.059	1.056	1.055	1.053	1.051	1.049	1.048	1.046	1.044	1.042	1.042	1.041	1.041	1.040	1.038	1.037	1.036	1.035	1.035	1.034
14	1.072	1.070	1.069	1.066	1.062	1.059	1.056	1.053	1.053	1.051	1.049	1.047	1.046	1.044	1.042	1.041	1.040	1.039	1.039	1.038	1.037	1.036	1.035	1.034	1.033	1.032
16	1.070	1.067	1.066	1.063	1.060	1.056	1.054	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.041	1.039	1.039	1.038	1.038	1.036	1.036	1.034	1.033	1.032	1.032	1.031
18	1.067	1.065	1.064	1.061	1.057	1.054	1.051	1.049	1.048	1.046	1.044	1.043	1.042	1.041	1.039	1.038	1.037	1.036	1.036	1.035	1.034	1.033	1.032	1.031	1.030	1.029
20	1.064	1.062	1.061	1.058	1.054	1.051	1.049	1.046	1.046	1.044	1.042	1.041	1.040	1.039	1.037	1.036	1.035	1.034	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028
22	1.061	1.059	1.058	1.055	1.052	1.049	1.046	1.044	1.044	1.042	1.040	1.039	1.038	1.036	1.035	1.034	1.033	1.032	1.032	1.031	1.030	1.030	1.029	1.028	1.028	1.027
24	1.058	1.056	1.055	1.052	1.049	1.046	1.044	1.042	1.042	1.040	1.038	1.037	1.036	1.034	1.033	1.032	1.032	1.031	1.031	1.030	1.029	1.028	1.027	1.026	1.026	1.025
26	1.055	1.053	1.052	1.049	1.047	1.044	1.042	1.039	1.039	1.037	1.036	1.036	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028	1.027	1.027	1.026	1.025	1.024	1.024
28	1.052	1.050	1.049	1.047	1.044	1.041	1.039	1.037	1.037	1.035	1.034	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.028	1.027	1.026	1.025	1.024	1.023	1.023	1.022
30	1.049	1.047	1.046	1.044	1.041	1.039	1.037	1.035	1.035	1.033	1.032	1.032	1.030	1.029	1.028	1.027	1.027	1.026	1.026	1.025	1.024	1.024	1.023	1.022	1.022	1.021
32	1.046	1.044	1.043	1.041	1.038	1.036	1.035	1.033	1.033	1.031	1.030	1.030	1.028	1.027	1.026	1.025	1.025	1.024	1.024	1.023	1.022	1.022	1.021	1.021	1.020	1.020
34	1.043	1.041	1.040	1.038	1.036	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.026	1.025	1.024	1.023	1.023	1.022	1.022	1.022	1.021	1.021	1.020	1.019	1.019	1.018
36	1.039	1.038	1.037	1.035	1.033	1.031	1.030	1.028	1.028	1.027	1.025	1.025	1.024	1.023	1.023	1.022	1.021	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017
38	1.036	1.035	1.034	1.032	1.031	1.029	1.027	1.026	1.025	1.025	1.023	1.023	1.022	1.021	1.021	1.020	1.020	1.019	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015
40	1.033	1.032	1.031	1.029	1.028	1.026	1.025	1.024	1.023	1.023	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017	1.017	1.016	1.016	1.015	1.015	1.014	1.014
42	1.030	1.029	1.028	1.027	1.025	1.024	1.023	1.022	1.021	1.021	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.013
44	1.027	1.026	1.025	1.023	1.022	1.021	1.020	1.019	1.019	1.018	1.017	1.017	1.016	1.016	1.015	1.014	1.014	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011
46	1.023	1.022	1.022	1.021	1.020	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.012	1.011	1.011	1.010	1.010	1.010	1.010
48	1.020	1.019	1.019	1.018	1.017	1.016	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.011	1.011	1.010	1.010	1.010	1.009	1.009	1.008	1.008
50	1.017	1.016	1.016	1.015	1.014	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.008	1.007	1.007	1.007	1.007
52	1.014	1.013	1.012	1.012	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005
54	1.010	1.010	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004
56	1.007	1.007	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
58	1.003	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001
60	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
62	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999	0.999
64	0.993	0.993	0.994	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.997	0.997	0.997	0.997
66	0.990	0.990	0.990	0.990	0.991	0.992	0.992	0.993	0.993	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996
68	0.986	0.986	0.987	0.987	0.988	0.989	0.990	0.990	0.990	0.990	0.991	0.991	0.991	0.992	0.992	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.994	0.994	0.994	0.994
70	0.983	0.983	0.984	0.984	0.985	0.986	0.987	0.988	0.988	0.988	0.989	0.989	0.989	0.990	0.990	0.991	0.991	0.991	0.991	0.992	0.992	0.992	0.992	0.993	0.993	0.993
72	0.979	0.980	0.981	0.981	0.982	0.983	0.984	0.985	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.989	0.989	0.990	0.990	0.990	0.991	0.991	0.992	0.992
74	0.976	0.976	0.977	0.978	0.980	0.980	0.982	0.983	0.983	0.984	0.985	0.985	0.985	0.986	0.986	0.987	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.990	0.990	0.990
76	0.972	0.973	0.974	0.975	0.977	0.978	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.984	0.985	0.986	0.986	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989
78	0.969	0.970	0.970	0.972	0.974	0.975	0.977	0.978	0.978	0.979	0.980	0.980	0.981	0.982	0.983	0.984	0.984	0.984	0.984	0.985	0.986	0.986	0.986	0.987	0.987	0.987
80	0.965	0.967	0.967	0.969	0.971	0.972	0.974	0.975	0.976	0.977	0.978	0.978	0.979	0.980	0.981	0.982	0.982	0.982	0.982	0.983	0.984	0.984	0.985	0.985	0.986	0.986
82	0.961	0.963	0.963	0.966	0.968	0.969	0.971	0.972	0.973	0.974	0.976	0.976	0.977	0.978	0.979	0.980	0.980	0.980	0.980	0.981	0.982	0.983	0.983	0.984	0.984	0.985
84	0.957	0.959	0.960	0.962	0.965	0.966	0.968	0.970	0.971	0.972	0.974	0.974	0.975	0.976	0.977	0.978	0.979	0.979	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.983
86	0.954	0.956	0.956	0.959	0.961	0.964	0.966	0.967	0.968	0.969	0.971	0.971	0.972	0.973	0.975	0.976	0.977	0.977	0.977	0.978	0.979	0.980	0.980	0.981	0.981	0.982
88	0.950	0.952	0.953	0.955	0.958	0.961	0.963	0.965	0.966	0.967	0.969	0.969	0.970	0.971	0.973	0.974	0.975	0.976	0.976	0.977	0.978	0.978	0.979	0.979	0.980	0.980
90	0.946	0.949	0.949	0.952	0.955	0.958	0.960	0.962	0.963	0.964	0.967	0.967	0.968	0.969	0.971	0.972	0.973	0.974	0.974	0.975	0.976	0.977	0.977	0.978	0.978	0.979
92	0.942	0.945	0.946	0.949	0.952	0.955	0.957	0.959	0.960	0.962	0.964	0.965	0.966	0.967	0.969	0.970	0.971	0.972	0.972	0.973	0.974	0.975	0.975	0.976	0.977	0.977
94	0.938	0.941	0.942	0.946	0.949	0.952	0.954	0.957	0.958	0.959	0.962	0.962	0.964	0.965	0.967	0.968	0.969	0.970	0.970	0.971	0.972	0.973	0.974	0.975	0.975	0.976
96	0.935	0.938	0.939	0.942	0.946	0.949	0.952	0.954	0.955	0.957	0.959	0.960	0.961	0.963	0.965	0.966	0.967	0.968	0.968	0.970	0.971	0.972	0.972	0.973	0.974	0.975
98	0.931	0.934	0.935	0.939	0.943	0.946	0.949	0.952	0.953	0.954	0.957	0.957	0.959	0.961	0.963	0.964	0.965	0.966	0.966	0.968	0.969	0.970	0.971	0.972	0.972	0.973
100	0.927	0.930	0.932	0.936	0.940	0.943	0.946	0.949	0.950	0.952	0.954	0.955	0.957	0.959	0.961	0.962	0.963	0.964	0.964	0.966	0.967	0.968	0.969	0.970	0.971	0.972
105	0.917	0.920	0.923	0.927	0.931	0.935	0.939	0.943	0.943	0.946	0.949	0.949	0.951	0.954												
110	0.907	0.911	0.913	0.918	0.923	0.927	0.932	0.936	0.937	0.939	0.943	0.944	0.946	0.949												
115	0.897	0.902	0.904	0.909	0.915	0.920	0.925	0.930	0.930	0.933	0.937	0.938	0.940	0.944												
120	0.887	0.892	0.894	0.900	0.907	0.912	0.918	0.923	0.924	0.927	0.931	0.932	0.934	0.938												
125	0.876	0.881	0.884	0.890	0.898	0.903	0.909	0.916	0.916	0.920	0.925	0.927	0.928	0.933												
130	0.865	0.871	0.873	0.880	0.888	0.895	0.901	0.908	0.909	0.913	0.918	0.921	0.923	0.927												
135	0.854	0.861	0.863	0.871	0.879	0.887	0.894	0.901	0.902	0.907	0.912	0.914	0.916	0.921												
140	0.842	0.850	0.852	0.861	0.870	0.879	0.886	0.893	0.895	0.900	0.905	0.907	0.910	0.915												

Table 2. Illustration for Use. Given the specific (60/60) 0.600 and temperature of measurement of 26° F. The volume correction factor to convert the volume at the measured temperature of 26° F to volume at 6° F is found by moving down the column headed 0.600 to intersect with the horizontal line from 26° F. The volume correction factor is 1.033.

Natural Gasoline Association of America.

N.G.A.A. SPECIFIC GRAVITY CONVERSION FACTORS (1942)

Observed Temperature Degrees Fahrenheit	OBSERVED SPECIFIC GRAVITY																																
	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73
	CORRESPONDING SPECIFIC GRAVITIES 60° F./60° F.																																
−50																0.487	0.500	0.513	0.526	0.538	0.550	0.562	0.575	0.587	0.599								
−45																0.491	0.504	0.517	0.529	0.542	0.554	0.566	0.578	0.590									
−40															0.483	0.495	0.508	0.521	0.533	0.545	0.558	0.570	0.581	0.593									
−35															0.487	0.500	0.512	0.525	0.537	0.549	0.561	0.573	0.585	0.596									
−30															0.491	0.504	0.516	0.529	0.541	0.552	0.564	0.576	0.588	0.600									
−25															0.496	0.508	0.520	0.532	0.544	0.556	0.568	0.580	0.591										
−20														0.488	0.500	0.512	0.524	0.536	0.548	0.559	0.571	0.583	0.594										
−15													0.492	0.504	0.516	0.528	0.540	0.552	0.563	0.574	0.586	0.597											
−10												0.484	0.496	0.508	0.520	0.532	0.543	0.555	0.566	0.578	0.589	0.601											
− 5												0.488	0.500	0.512	0.524	0.536	0.547	0.559	0.570	0.581	0.593												
0											0.481	0.493	0.505	0.516	0.528	0.540	0.551	0.562	0.573	0.585	0.596	0.607	0.618	0.628	0.639	0.649	0.659	0.670	0.680	0.690	0.700	
2											0.483	0.495	0.506	0.517	0.529	0.541	0.552	0.563	0.574	0.586	0.597	0.608	0.619	0.629	0.640	0.650	0.660	0.671	0.681	0.691	0.701	
4											0.484	0.496	0.508	0.519	0.531	0.542	0.553	0.564	0.576	0.587	0.598	0.609	0.620	0.630	0.641	0.651	0.661	0.672	0.682	0.692	0.702	
6											0.486	0.498	0.509	0.520	0.532	0.544	0.555	0.566	0.577	0.589	0.599	0.610	0.621	0.631	0.642	0.652	0.662	0.673	0.683	0.693	0.703	
8											0.487	0.499	0.511	0.522	0.534	0.545	0.556	0.567	0.579	0.590	0.600	0.611	0.622	0.632	0.643	0.653	0.663	0.674	0.684	0.694	0.704	
10											0.489	0.501	0.512	0.523	0.535	0.546	0.557	0.568	0.580	0.591	0.601	0.612	0.623	0.633	0.644	0.654	0.664	0.675	0.685	0.695	0.705	
12											0.491	0.503	0.514	0.525	0.536	0.547	0.558	0.569	0.581	0.592	0.602	0.613	0.624	0.634	0.645	0.655	0.665	0.676	0.686	0.696	0.706	
14											0.492	0.504	0.515	0.526	0.538	0.549	0.560	0.571	0.582	0.593	0.604	0.614	0.625	0.635	0.646	0.656	0.666	0.677	0.687	0.697	0.707	
16											0.494	0.506	0.517	0.528	0.539	0.550	0.561	0.572	0.584	0.595	0.605	0.616	0.626	0.637	0.647	0.657	0.667	0.678	0.688	0.698	0.708	
18											0.495	0.507	0.518	0.529	0.541	0.552	0.563	0.574	0.585	0.596	0.607	0.617	0.627	0.638	0.648	0.658	0.668	0.679	0.689	0.699	0.709	
20										0.486	0.497	0.509	0.520	0.531	0.542	0.553	0.564	0.575	0.586	0.597	0.608	0.618	0.628	0.639	0.649	0.659	0.669	0.680	0.690	0.700	0.710	
22										0.488	0.499	0.511	0.522	0.533	0.544	0.554	0.565	0.576	0.587	0.598	0.609	0.619	0.629	0.640	0.650	0.660	0.670	0.681	0.691	0.701		
24										0.490	0.501	0.512	0.523	0.534	0.545	0.556	0.567	0.578	0.588	0.599	0.610	0.620	0.630	0.641	0.651	0.661	0.671	0.682	0.692	0.702			
26										0.491	0.502	0.514	0.525	0.536	0.547	0.557	0.568	0.579	0.590	0.600	0.611	0.621	0.632	0.642	0.652	0.662	0.673	0.683	0.693	0.703		
28										0.493	0.504	0.515	0.526	0.537	0.548	0.559	0.570	0.581	0.591	0.601	0.612	0.622	0.633	0.643	0.653	0.663	0.674	0.684	0.694	0.704		
30										0.484	0.495	0.506	0.517	0.528	0.539	0.550	0.560	0.571	0.582	0.592	0.602	0.613	0.623	0.634	0.644	0.654	0.664	0.675	0.685	0.695	0.705		
32										0.486	0.497	0.508	0.519	0.530	0.540	0.551	0.561	0.572	0.583	0.593	0.603	0.614	0.624	0.635	0.645	0.655	0.665	0.676	0.686	0.696	0.706		
34										0.488	0.499	0.509	0.520	0.531	0.542	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.626	0.636	0.646	0.656	0.666	0.677	0.687	0.697	0.707		
36										0.489	0.500	0.511	0.522	0.533	0.543	0.554	0.564	0.575	0.586	0.596	0.606	0.617	0.627	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708		
38										0.491	0.502	0.512	0.523	0.534	0.545	0.556	0.566	0.577	0.587	0.598	0.608	0.618	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709		
40									0.483	0.493	0.504	0.514	0.525	0.536	0.546	0.557	0.567	0.578	0.588	0.599	0.609	0.619	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710		
42									0.485	0.495	0.506	0.516	0.527	0.537	0.547	0.558	0.568	0.579	0.589	0.600	0.610	0.620	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701			
44									0.486	0.497	0.507	0.517	0.528	0.539	0.549	0.559	0.570	0.580	0.591	0.601	0.611	0.621	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702		
46									0.488	0.498	0.509	0.519	0.530	0.540	0.550	0.561	0.571	0.582	0.592	0.603	0.613	0.623	0.633	0.643	0.653	0.663	0.673	0.683	0.693	0.703		
48									0.489	0.500	0.510	0.520	0.531	0.542	0.552	0.562	0.573	0.583	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.664	0.674	0.684	0.694	0.704		
50								0.480	0.491	0.502	0.512	0.522	0.533	0.543	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.665	0.675	0.685	0.695	0.705		
52								0.482	0.493	0.504	0.514	0.524	0.534	0.544	0.554	0.564	0.575	0.585	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.666	0.676	0.686	0.696	0.706		
54								0.484	0.494	0.505	0.515	0.525	0.536	0.546	0.556	0.566	0.576	0.586	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.667	0.677	0.687	0.697	0.707		
56								0.486	0.496	0.507	0.517	0.527	0.537	0.547	0.557	0.567	0.578	0.588	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708		
58								0.488	0.498	0.508	0.518	0.529	0.539	0.549	0.559	0.569	0.579	0.589	0.599	0.609	0.619	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709		
60							0.480	0.490	0.500	0.510	0.520	0.530	0.540	0.550	0.560	0.570	0.580	0.590	0.600	0.610	0.620	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710		
62							0.482	0.492	0.502	0.512	0.522	0.532	0.541	0.551	0.561	0.571	0.581	0.591	0.601	0.611	0.621	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701			
64							0.484	0.494	0.504	0.513	0.523	0.533	0.543	0.553	0.563	0.573	0.582	0.592	0.602	0.612	0.622	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702			
66							0.485	0.495	0.505	0.515	0.525	0.535	0.544	0.554	0.564	0.574	0.584	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.663	0.673	0.683	0.693	0.703			
68							0.487	0.497	0.507	0.517	0.526	0.536	0.546	0.556	0.566	0.576	0.585	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.664	0.674	0.684	0.694	0.704			
70						0.479	0.489	0.499	0.509	0.518	0.528	0.538	0.547	0.557	0.567	0.577	0.586	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.665	0.675	0.685	0.695	0.705			
72						0.481	0.491	0.501	0.511	0.520	0.529	0.539	0.549	0.558	0.568	0.578	0.587	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.666	0.676	0.686	0.696	0.706			
74						0.483	0.493	0.502	0.512	0.521	0.531	0.541	0.550	0.560	0.569	0.579	0.589	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.667	0.677	0.687	0.697	0.707			
76						0.484	0.494	0.504	0.513	0.523	0.532	0.542	0.551	0.561	0.571	0.581	0.590	0.600	0.610	0.620	0.629	0.639	0.649	0.659	0.668	0.678	0.688	0.698	0.708			
78						0.486	0.496	0.505	0.515	0.524	0.534	0.544	0.553	0.563	0.572	0.582	0.592	0.601	0.611	0.621	0.630	0.640	0.650	0.660	0.669	0.679	0.689	0.699	0.709			
80					0.479	0.488	0.498	0.507	0.517	0.526	0.535	0.545	0.554	0.564	0.573	0.583	0.593	0.602	0.612	0.622	0.631	0.641	0.651	0.661	0.670	0.680	0.690	0.700	0.710			
82					0.481	0.490	0.500	0.509	0.519	0.528	0.537	0.546	0.555	0.565	0.574	0.584	0.594	0.603	0.613	0.623	0.632	0.642	0.652	0.662	0.671	0.681	0.691	0.701			
84					0.483	0.492	0.501	0.510	0.520	0.529	0.538	0.548	0.557	0.567	0.576	0.585	0.595	0.604	0.614	0.624	0.633	0.643	0.653	0.663	0.672	0.682	0.692	0.702			
86					0.484	0.493	0.503	0.512	0.521	0.531	0.540	0.549	0.558	0.568	0.577	0.587	0.597	0.606	0.616	0.625	0.635	0.644	0.654	0.664	0.673	0.683	0.693	0.703			
88					0.486	0.495	0.504	0.513	0.523	0.532	0.541	0.551	0.560	0.569	0.579	0.588	0.598	0.607	0.617	0.626	0.636	0.645	0.655	0.665	0.674	0.684	0.694	0.704			
90				0.479	0.488	0.497	0.506	0.515	0.524	0.534	0.543	0.552	0.561	0.570	0.580	0.589	0.599	0.608	0.618	0.627	0.637	0.646	0.656	0.666	0.675	0.685	0.695	0.705				
92				0.481	0.490	0.499	0.508	0.517	0.526	0.535	0.544	0.553	0.562	0.572	0.581	0.590	0.600	0.609	0.619	0.628	0.638	0.647	0.657	0.667	0.676	0.686	0.696	0.706				
94				0.483	0.492	0.500	0.509	0.518	0.528	0.537	0.545	0.554	0.563	0.573	0.582	0.591	0.601	0.610	0.620	0.629	0.639	0.648	0.658	0.668	0.677	0.687	0.697	0.707				
96				0.484	0.493	0.502	0.511	0.520	0.529	0.538	0.547	0.556	0.565	0.574	0.584	0.593	0.602	0.612	0.621	0.630	0.640	0.649	0.659	0.669	0.678	0.688	0.698	0.708				
98				0.486	0.495	0.503	0.512	0.521	0.531	0.540	0.548	0.557	0.566	0.575	0.585	0.594	0.603	0.613	0.622	0.631	0.641	0.650	0.660	0.670	0.679	0.689	0.699	0.709				
100			0.480	0.488	0.497	0.505	0.514	0.523	0.532	0.541	0.549	0.558	0.567	0.577	0.586	0.595	0.604	0.614	0.623	0.632	0.642	0.651	0.661	0.671	0.680	0.690	0.700	0.710				
105			0.485	0.493	0.502	0.510	0.518	0.527	0.535	0.544	0.553	0.562	0.571	0.580	0.589	0.598																
110		0.481	0.489	0.497	0.506	0.514	0.522	0.530	0.539	0.548	0.557	0.565	0.574	0.583	0.592																
115		0.485	0.493	0.501	0.510	0.518	0.526	0.534	0.543	0.551	0.560	0.568	0.577	0.586	0.595																
120	0.482	0.489	0.497	0.505	0.513	0.521	0.529	0.538	0.546	0.554	0.563	0.571	0.580	0.589	0.598																
125	0.486	0.494	0.502	0.509	0.517	0.525	0.533	0.541	0.550	0.558	0.566	0.574	0.583	0.592																	
130	0.491	0.498	0.506	0.514	0.521	0.529	0.537	0.545	0.553	0.561	0.569	0.577	0.586	0.595																	
135	0.495	0.502	0.510	0.517	0.525	0.533	0.541	0.549	0.557	0.565	0.573	0.581	0.589	0.598																	
140	0.499	0.506	0.514	0.521	0.529	0.536	0.544	0.552	0.560	0.568	0.576	0.584	0.592	0.601																	

Table 1. Illustration for Use. Given the specific gravity (t/60) 0.620 at 26° F. The specific gravity 60/60 will be found by moving down the column headed 0.620 to intersect with the horizontal lines from 26° F. The specific gravity 60/60 is found to be 0.600.

Natural Gasoline Association of America.

Engine horsepower: Engine horsepower is taken as 33,000 foot-pounds of work in one minute, or 550 foot-pounds of work in one second. To express indicated horsepower the following formula is used:

$$\text{ihp} = \frac{\text{mep LAN}}{33{,}000}$$

Where:

mep is the mean effective pressure (as shown by a steam engine indicator diagram) in pounds per square inch, acting on the piston.

L is the length of the stroke in feet.

A is the area of the piston in square inches (area of the piston rod to be deducted for the crank end).

N is the number of working strokes per minute (in double-acting steam engines it will be twice the number of revolutions).

Indicated horsepower of gas engines: The same formula is used for this calculation, except that the symbol N represents the total number of explosions per minute in all cylinders.

In computations for four-stroke cycle, single cylinder, single-acting gas engines firing every fourth stroke, this will be the revolutions per minute, divided by two. For two-stroke cycle, single cylinder, single-acting engines, firing every second stroke, or once every revolution, the value of N will be represented by the number of revolutions per minute.

Brake horsepower is the power out-put of the engine, measured at the fly wheel or main shaft. It is the actual amount of energy which may be delivered by the engine to drive compressors, generators, etc. Brake horsepower is expressed by the following equation:

$$\text{BHP} = \frac{\text{T} \times \text{RPM}}{5255}$$

Where:

RPM is shaft speed in revolutions per min.

T is the torque in foot-pounds. Torque is normally measured by dynamometers, prony brake or other engine test devices.

Where the engine is assembled in a unit including clutch, transmission and engine accessories, the power out-put is termed UNIT HORSEPOWER. Unit horsepower is measured in the same manner as brake horsepower and the expression for brake horsepower is used.

Where the horsepower and shaft speed is known, the TORQUE may be determined by the following equation:

$$\text{TORQUE} = \frac{\text{HP} \times 5255}{\text{RPM}}$$

Electrical horsepower: The unit for measuring the electrical horsepower input to a motor is the watt. For direct current this is the product of the volts E and the amperes I, measured at the motor terminals, and is represented as $W = EI$. Since 746 watts are equivalent to an electrical horsepower, the following formula represents the above relations:

$$\text{HP} = \frac{EI}{746}$$

Should the power used be taken from an alternating current system, the conditions as outlined below will hold.

If W =watts, E = average volts between terminals, I = average line current, and pf = power factor expressed as a decimal fraction, the following formulae represent their relations:

$$\text{Single phase HP} = \frac{EI \times pf}{746}$$

$$\text{Two phase HP} = \frac{2\,EI \times pf}{746}$$

$$\text{Three phase HP} = \frac{1.732\,EI \times pf}{746}$$

MOTOR SPEED. The synchronous speed of AC motors is determined by the number of poles and frequency.

$$\text{Synchronous speed} = \frac{120 \times f}{p}$$

where

f = frequency in cycles

p = number of poles of the motor

Induction motors will have full load speeds of from 2 to 6 per cent less than the above, average 4 per cent less.

DC motors will have standard full-load speeds when hot of: 575, 850, 1150, 1750, and 3500 rev per min (rpm).

At normal temperature, rated load, and voltage the variation above or below the above full-load motor speeds may not exceed 7½% in motors up to 7½ hp at 1150 rpm 5% in motors larger than 7½ hp at 1150 rpm.

The above relations are based upon the energy delivered to the motor as electrical power. The approximate horsepower delivered by the motor may be determined by multiplying the above horsepower values by the motor efficiency.

$$\text{HP (delivered)} = \text{Eff.} \times \text{HP (input)}$$

EFFICIENCIES OF ELECTRIC MOTORS

Average Efficiencies for Voltages up to 550 in Three Phase Motors

	Induction Motors		
Rating	Full load	¾ Load	½ Load
1 to 2 Hp.....	81	79	76
3 to 5 Hp.....	85	84	82
10 to 25 Hp.....	87.5	87	85
25 to 50 Hp.....	89	88.5	86.5
75 Hp.-100 Hp...	91	90	88
150-200 Hp.....	92	91.5	89.5
Above 200 Hp....	93.5	93	91

	Unity P. F. Syn. Motors		
Rating	Full load	¾ Load	½ Load
25 to 50 Hp.....	90	88.5	85
75 Hp.-100 Hp...	92	91	88
150-200 Hp.....	93	92	89.5
Above 200 Hp....	94.5	93.5	92

The above are averages for 1200 and 1800 RPM motors.

Low speed motors.—Efficiencies will be from 1 to 2% lower—2200 volt motors 100 HP and above have approximately the same efficiency as low voltage motors. On smaller sizes the 2200 volt motors have efficiencies 1 to 3% lower.

BOILER HORSEPOWER. The equivalent evaporation of 34.5 pounds of water per hour from a feed water temperature of 212 deg F into steam at the same temperature is a boiler horsepower. Since the actual operating conditions of a boiler are seldom "from and at 212 deg F" a factor is needed to convert the rating from the actual conditions to what they would be "from and at 212 deg." This is called the "factor of evaporation" and equals ratio of the heat required to generate 1 pound of steam under actual conditions to that required to make 1 pound of steam "from and at 212 deg F."

With small boilers in industrial plants, heat liberations of approximately 15,000 Btu per cu ft of furnace volume per hour are attained, whereas, in large central stations, this can run up to 30,000 Btu per cu ft or higher.

The horsepower rating of a boiler is based on its heating surface, 10 square feet of heating surface being allowed per rated horsepower.

The relation between heat liberation, heating surface, per cen rating, and boiler efficiency is as follows:

$$\text{Heat liberation per hr} = \frac{\text{Heating Surface} \times 33{,}500 \times \%\ \text{Rating}}{10 \times \%\ \text{efficiency}}$$

The information on horsepower calculation, motors, steam and steam boilers is published through courtesy of "Compressed Air Data" and "Cameron Pump Data."

WATER HORSEPOWER FORMULAS

$$\text{Water HP} = \frac{\text{gal per min} \times \text{head in feet} \times \text{specific gravity}}{3960}$$

$$\text{or Water HP} = \frac{\text{gal per min} \times \text{head in lbs per sq in}}{1714}$$

$$\text{Brake HP} = \frac{\text{Water HP}}{\text{Efficiency of Pump}}$$

$$\text{Kw hrs per 1000 gal cold water pumped per hour} = \frac{\text{head in feet of water} \times 0.00315}{\text{efficiency of pump} \times \text{efficiency of motor}}$$

Cameron Hydraulic Data.

POWER REQUIREMENTS OF POSITIVE BLOWERS AND EXHAUSTERS

$$\text{BHP} = .00474 \times D \times \text{RPM} \times P$$

Where

BHP equals horsepower required to drive the blower or exhauster.

D equals displacement in cubic feet per revolution.

RPM equals revolutions per minute.

P equals outlet minus inlet pressure in pounds per square inch. (If inlet pressure is atmospheric, then P in the outlet gage pressure.)

Note: This formula assumes a mechanical efficiency of 92 per cent for the blower or exhauster.

Volumetric efficiency is provided for since actual capacity is less than actual RPM multiplied by displacement.

Engineering Tables — Roots-Connersville.

Theoretical Compression. In compressing a gas, if the heat is removed so as to keep its temperature constant, it is called Isothermal Compression.

If all the heat of compression is retained in the gas and used to increase its temperature, it is called Adiabatic Compression.

In present-day reciprocating compressors, the air or gas is compressed very nearly adiabatically. The water-jacketing brings the compression curve somewhat below the adiabatic, but the excess pressure required to force the air or gas through the valves makes the work done very close to that which would be calculated on the assumption of adiabatic compression for the entire cylinder of air or gas.

The following formulae apply to adiabatic compression:

$$m\,e\,p = \frac{n}{n-1} P_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$i\,hp = \frac{m\,ep \times L\,A\,N}{33{,}000}$$

Where

m e p = mean effective pressure in compressor cylinder.
i h p = indicated horsepower
n = ratio of the specific heat a constant pressure to the specific heat at constant volume for air or the gas being compressed (see the table opposite).
P_1 = inlet pressure—pounds per square inch absolute.
P_2 = discharge pressure—pounds per square inch absolute.
$r = \frac{P_2}{P_1}$
L = length of stroke of compressor in feet.
A = effective area of cylinder in square inches.
N = number of strokes per minute.

For adiabatic compression of air in a single stage:

$$\left.\begin{matrix} \text{i h p per 100 cu ft} \\ \text{piston displacement} \\ \text{per min} \end{matrix}\right\} = 1.51\ P_1\ (r^{0.29} - 1)$$

Since the values of n for the principal constituents of manufactured gas do not differ substantially from that for air this formula may be applied to manufactured gas.

For natural gas (when n = 1.275) the corresponding formula would be:

$$\left.\begin{matrix} \text{i h p per 100 cu ft} \\ \text{piston displacement} \\ \text{per min} \end{matrix}\right\} = 2.023\ P_1 (r^{0.216} - 1)$$

Indicated horsepower must be divided by overall efficiency to obtain brake or delivered horsepower.

Compression Temperatures

For adiabatic compression

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = r^{\frac{n-1}{n}}$$

Where

T_1 = absolute inlet temperature.
T_2 = absolute discharge temperature.
P_1, P_2 and r as indicated above.

Values of n for certain gases are as follows:

Acetylene	1.26
Air	1.403
Ammonia	1.310
Butane	1.108
Carbon Dioxide	1.304
Carbon Monoxide	1.404
Ethane	1.22
Ethylene	1.255
Hydrogen	1.410
Methane	1.31
Nitrogen	1.404
Oxygen	1.401
Propane	1.15
Water Vapor	1.324

Theoretical horse power required to compress 100 cu ft of air from atmospheric pressure (14.7 lb) to various gauge pressures:

Adiabatic compression

Discharge Pressure lbs. gauge	H. P. Single stage	H. P. Two stage	Discharge Pressure lbs. gauge	H. P. Single stage	H. P. Two stage
5	1.9	....	80	15.9	13.7
10	3.6	....	90	16.9	14.5
15	5.0	....	100	18.0	15.4
20	6.2	....	120	19.9	16.8
25	7.4	....	140	21.6	18.0
30	8.4	....	160	....	19.1
35	9.4	....	180	....	20.1
40	10.3	....	200	....	21.0
45	11.1	....	250	....	23.0
50	11.9	....	300	....	24.7
55	12.6	....	400	....	27.6
60	13.3	....	500	....	29.8
65	14.0	....	600	....	31.7
70	14.6	12.8	...	....	....
75	15.3	13.3	...	....	....

Theoretical temperatures reached in compressing gas from atmospheric pressure (14.7 lb) and 60 F to various gauge pressures.

Discharge pressure	Discharge temperatures Single stage Mf'd gas	Discharge temperatures Single stage Natural gas	Discharge temperatures Two stage Mf'd gas	Discharge temperatures Two stage Natural gas
5	106°	94°	...	...
10	144°	121°	...	...
15	177°	145°	...	...
20	207°	166°	...	...
25	234°	184°	...	...
30	258°	201°	...	...
35	280°	216°	...	...
40	301°	230°	...	...
45	320°	243°	177°	145°
50	339°	256°	185°	150°
55	356°	267°	191°	155°
60	373°	279°	198°	160°
65	389°	289°	204°	164°
70	404°	299°	210°	168°
75	419°	308°	216°	172°
80	432°	317°	221°	176°
90	459°	334°	231°	183°
100	484°	351°	240°	189°
120	533°	379°	257°	200°
140	569°	405°	272°	211°
160	...	...	285°°	219°
180	...	...	296°	227°
200	...	...	307°	235°
250	...	...	331°	250°
300	...	...	351°	264°

Figures for manufactured gas are also applicable to air. Actual discharge temperatures will be somewhat less than the above figures because of radiation and of heat carried off by the cooling water from the cylinder jackets.

Approximate Brake Horse Power Required by Air Compressors per 100 cu ft of free air actually delivered.

Altitude feet	Single stage psig			Two stage psig			
	60	80	100	60	80	100	125
0	16.3	19.5	22.1	14.7	17.1	19.1	21.3
1000	16.1	19.2	21.7	14.5	16.8	18.7	20.9
2000	15.9	18.9	21.3	14.3	16.5	18.4	20.5
3000	15.7	18.6	20.9	14.0	16.1	18.0	20.0
4000	15.4	18.2	20.6	13.8	15.8	17.7	19.6
5000	15.2	17.9	20.3	13.5	15.5	17.3	19.2

Actual Delivery. The actual delivery of a single-stage compressor pumping to 100 lbs. gauge from atmosphere will be from 65 per cent to 80 per cent of its piston displacement, depending upon its clearance space and valve gear. A compound machine compressing to 100 lbs. gauge with an inter-cooler pressure of about 27 lbs. gauge will deliver from 80 per cent to 90 per cent of its piston displacement.

Displacement. A convenient formula for calculating the displacement of a double acting cylinder is — square of the Diameter (inches) × stroke (inches) × R. P. M. × .0009 = piston displacement (c.f.m.). This makes a reasonable allowance for the piston rod on all piston sizes from about 5″ diam. to about 30″ diam.

Data on Compression from "Compressed Air Data," Ingersoll-Rand Co.

Two Stage Compression. Two stage compression is generally used where the compression ratio r is in excess of 5 or 6. An intercooler is used between the two stages.

To secure the desired pressure with minimum work, equal work should be done in the two stages and the intermediate temperature of the gas should be reduced to that at the inlet.

Then $P_{Intermediate}$ should be $\sqrt{P_1 \times P_2}$

Also the compression ratio in each stage should equal the square root of the over-all compression ratio.

For manufactured gas (2 stage compression):

$$\left.\begin{array}{l}\text{Total i.h.p. per 100 cu.}\\ \text{ft. piston displacement}\\ \text{per min.}\end{array}\right\} 3.02P_1\,(r^{0.145} - 1)$$

For natural gas (2 stage compression with n = 1.275):

$$\left.\begin{array}{l}\text{Total i.h.p. per 100 cu.}\\ \text{ft. piston displacement}\\ \text{per min.}\end{array}\right\} 4.046\,(r^{0.108} - 1)$$

BRAKE HORSE POWER FORMULA

for compressing natural gas

$$BHP = \frac{R}{R + JP_2} \times \frac{5.16 \quad 124 \log. R}{0.97 - 0.03R}$$

where

BHP = brake horse power required to compress one million cu ft of natural gas per day

R = ratio of compression $= \frac{P_1}{P_2}$

P_1 = compressor discharge, psia

P_2 = compressor suction, psia

J = factor for supercompressibility (assumed .022 per 100 psia)

BHP PER MILLION CU FT OF GAS COMPRESSED

Ratio of Compression	BHP Per Million C.F. per Day		Ratio of Compression	BHP Per Million C.F. per Day		Ratio of Compression	BHP Per Million C.F. per Day	
	Natural Gas	Manufactured Gas		Natural Gas	Manufactured Gas		Natural Gas	Manufactured Gas
1.2	15.5	15.5	2.8	63.0	65.0	4.4	93.5	98.0
1.3	20.5	20.5	2.9	65.5	67.5	4.5	95.5	100.0
1.4	25.0	25.0	3.0	67.5	70.0	4.6	97.0	101.5
1.5	28.5	29.0	3.1	69.5	72.0	4.7	99.0	103.5
1.6	32.0	32.5	3.2	71.5	74.0	4.8	101.0	106.0
1.7	35.5	36.5	3.3	73.5	76.5	4.9	102.5	107.5
1.8	38.5	39.5	3.4	75.5	78.0	5.0	104.0	109.5
1.9	41.5	42.0	3.5	77.5	80.5	5.1	106.0	111.5
2.0	44.0	45.0	3.6	79.0	82.5	5.2	107.5	113.0
2.1	46.5	47.5	3.7	81.0	84.5	5.3	109.0	115.0
2.2	49.0	50.5	3.8	83.0	86.5	5.4	110.5	116.5
2.3	51.5	53.0	3.9	84.5	88.5	5.5	112.5	118.5
2.4	54.0	55.5	4.0	86.5	90.5	5.6	114.0	120.0
2.5	56.5	58.0	4.1	88.5	92.5	5.7	115.5	122.0
2.6	58.5	60.5	4.2	90.5	94.0	5.8	117.0	124.0
2.7	61.0	63.0	4.3	92.0	96.0	5.9	118.5	125.5
						6.0	120.0	127.0

Clark Bros. Company

GAS FLOW FORMULAS

HIGH PRESSURE GAS FLOW. The Weymouth formula. This is considered to be the best known and most widely used formula. The original formula is as follows:

$$Q = 433.5 \frac{T_o}{P_o}\left[\frac{(P_1^2 - P_2^2)\,d^{16/3}}{GTL}\right]^{1/2}$$

where

Q = flow cubic feet per day under standard conditions (P_o and T_o)

d = internal diameter of pipe, inches

T_o = standard absolute temperature °F

T = temperature of flowing gas—absolute °F

P_o = standard pressure, psia

P_1 = initial pressure, psia

P_2 = terminal pressure, psia

G = specific gravity of gas, air = 1.0

L = length of pipe line, miles

By assuming

$T_o = 60 + 460 = 520$ F

$P_o = 14.73$ psia

$T = 50 + 460 = 510$ F

the above formula is simplified to:

$$Q = 676.2\sqrt{\frac{(P_1^2 - P_2^2)\,d^{16/3}}{GL}}$$

or

$$Q = 676.2\, d^{8/3}\sqrt{\frac{P_1^2 - P_2^2}{GL}}$$

The above formula assumes that gas acts inaccordance with the perfect gas laws. Since the deviation from the ideal gas relations is not normally significant with pressures below 200 psi, the formulas are considered applicable to pipe line calculations up to line pressures of 200 psi.

Where pressures in excess of the above value, correction for supercompressibility should be applied.

Loop Line Equivalents: A line composed of several lengths L_1, L_2, etc., of diameters d_1, d_2, etc., can be transformed into a single equivalent line of uniform diameter d_o, by determining the equivalent length of each individual section by means of formula $L_{o,1} = L_1\left(\frac{d_o}{d_1}\right)^{5\ 1/3}$ and adding these equivalent section lengths together to form an equivalent line of diameter d_o and total length L_o.

To transform a length of pipe of diameter d and length L, to a pipe of equivalent capacity having a length L_o, the diameter of the equivalent section will be $d_o = d\left(\frac{L_o}{L}\right)^{3/16}$.

The diameter of a single pipe having a capacity equivalent to the aggregate capacity of several parallel, or looped lines of a common length and of diameters d_1, d_2, etc., is equal to

$$d_o = [d_1^{8/3} + d_2^{8/3} + \text{— etc.,}]^{3/8} = [\Sigma\, d^{8/3}]^{8/3}.$$

If the several loops have different lengths, the actual diameters of the loops must first be transfored into equivalent diameters of pipe having a common length and these equivalent diameters then be added in accordance with the formula just given.

Values of $(d)^{8/3}$ and $(d)^{16/3}$

(Note — $d^{8/3} = \sqrt{d^{16/3}}$)

Diameter (d), inches			
External	Internal	$(d)^{8/3}$	$(d)^{16/3}$
2.375	2.067	6.933	48.063
3.500	3.068	19.87	394.99
4.500	4.026	41.02	1,682.6
6.625	6.040	121.0	14,640
6.625	6.125	125.6	15,773
6.625	6.250	132.5	17,567
8.625	8.071	262.1	68,700
8.625	8.125	266.8	71,182
8.625	8.185	272.1	74,035
10.000	9.625	419.2	175,710
10.750	10.192	488.3	238,440
10.750	10.250	495.7	245,760
12.750	12.090	770.0	592,870
12.750	12.188	786.7	618,920
12.750	12.250	797.5	635,930
14.000	13.500	1033.3	1,067,600
15.000	14.500	1250.2	1,563,000
16.000	15.250	1430.2	2,045,400
16.000	15.375	1461.7	2,136,500
16.000	15.500	1493.5	2,230,600
18.000	17.250	1986.6	3,946,500
18.000	17.375	2025.3	4,101,600
18.000	17.500	2064.3	4,261,400
20.000	19.250	2661.6	7,084,200
20.000	19.375	2707.9	7,333,000
20.000	19.432	2729.3	7,449,200
22.000	21.125	3410.4	11,631,000
22.000	21.375	3519.1	12,384,000
22.000	21.500	3574.1	12,775,000
24.000	23.125	4340.8	18,843,000
24.000	23.375	4466.8	19,953,000
24.000	23.500	4531.0	20,529,000
26.000	25.125	5415.4	29,326,000
26.000	25.500	5633.4	31,736,000
28.000	27.125	6642.3	44,120,000
28.000	27.500	6889.8	47,471,000
30.000	29.125	8030.0	64,482,000
30.000	29.500	8308.3	69,030,000

Formula for Determining Mean Pressure (P_M) in Pipe Line

$$P_M = \tfrac{2}{3}\left(P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right)$$

Supercompressibility Factor

If a flow formula, which does not reflect the deviation from the ideal gas law, is used for problems involving pressures above 200 lbs., its results may be corrected by applying the following supercompressibility factor.

$$\text{Supercompressibility Factor} = \sqrt{1 + .0002P_M}$$

PANHANDLE FORMULA

This formula is used by many companies for the calculation of gas flow in large diameter (12 in. and larger) transmission lines.

BASIC PANHANDLE FORMULA

$$Q = 435.87e\left(\frac{T_o}{P_o}\right)^{1.07881}\left(\frac{(P_1^2 - P_2^2)}{G^{0.8539}T_fL}\right)^{0.5394} d^{2.6182}$$

Substituting:

T_o = Base temperature = 60° + 460° = 520° abs
P_o = Base pressure = 14.73 psia
T_f = Flowing temperature = 50° + 460° = 510° abs
G = Gravity of gas = 0.686 (Panhandle gas)

and where:

P_1 = Initial pressure—psia
P_2 = Final pressure—psia
L = Length of line in miles
d = Diameter of pipe in inches
e = Experience factor

the equation can be resolved to:

$$Q/d^{2.6182} = 839.51e\left(\frac{(P_1^2 - P_2^2)}{L}\right)^{0.5394}$$

CLARK FORMULA

$$Q = \frac{80.8}{\rho_o \mu^{0.0814}}\left[\frac{D^{4.85}M(P_1^2-P_2^2)}{L\,Z_{av}\,T}\right]^{0.541} E,$$

where Q = quantity of gas transported in cubic feet per day measured at P_o and T_o

ρ_o = Density of gas, pounds per cubic foot at P_o and T_o
μ = Absolute viscosity of gas, pounds per foot-second.
D = Inside diameter of pipe, inches.
M = Molecular weight of gas, pounds per mole.
P_1 = Discharge pressure from compressors, lb per sq in. abs.
P_2 = Suction pressure to compressors, lb per sq in. abs.
L = Distance between compressor stations, miles.
Z_{av} = Average deviation factor.
T = Flowing temperature, °R.
E = Experience factor for adjustment of formula.

For any gas line which is normally handling the same type of fluid at approximately constant temperature, the equation may be simplified by combining into a single term the expression for the gas density, the gas viscosity, molecular weight, temperature, and the numerical constant. Under normal conditions, the viscosity term will not influence the results greatly because a 30 per cent change in absolute value of the viscosity will cause only about 2.7 per cent change in the computed quantity of gas flowing. Thus, once the gas viscosity is determined for an operating line, small variations from the conditions under which it was determined will not influence the accuracy of the equation appreciably. The condensed form of the equation is then:

$$Q = K_2\left[\frac{D^{4.85}\,P_1^2\,(1 - 1/Cr^2)}{L\,Z_{av}}\right]^{0.541} E,$$

where $K_2 = \frac{80.8}{\rho_o \mu^{0.0814}}\left[\frac{M}{T}\right]^{0.541}$,

and Cr = Compression ratio, P_1/P_2

"High Pressure Pipe Line Research." Copyright 1942, Clark Bros. Co., Inc.

LOW PRESSURE GAS FLOW

For distribution system problems the Spitzglass formulas are:

FOR PRESSURES NOT EXCEEDING ONE POUND GAUGE:

$$Q = 3550\,K\left(\frac{h}{S\,L}\right)^{1/2}$$

Where:

Q = Flow per hour in cubic feet of gas at 14.73 psi absolute (30" Hg.) and 60 F.
H = Pressure drop in inches of water column.
S = Specific gravity of gas. Air = 1.0.
L = Length of pipe in feet.
d = Internal diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

FOR PRESSURES EXCEEDING ONE POUND GAUGE:

$$Q = 4830\,K\left(\frac{Pa}{SL}\right)^{1/2}$$

Where:

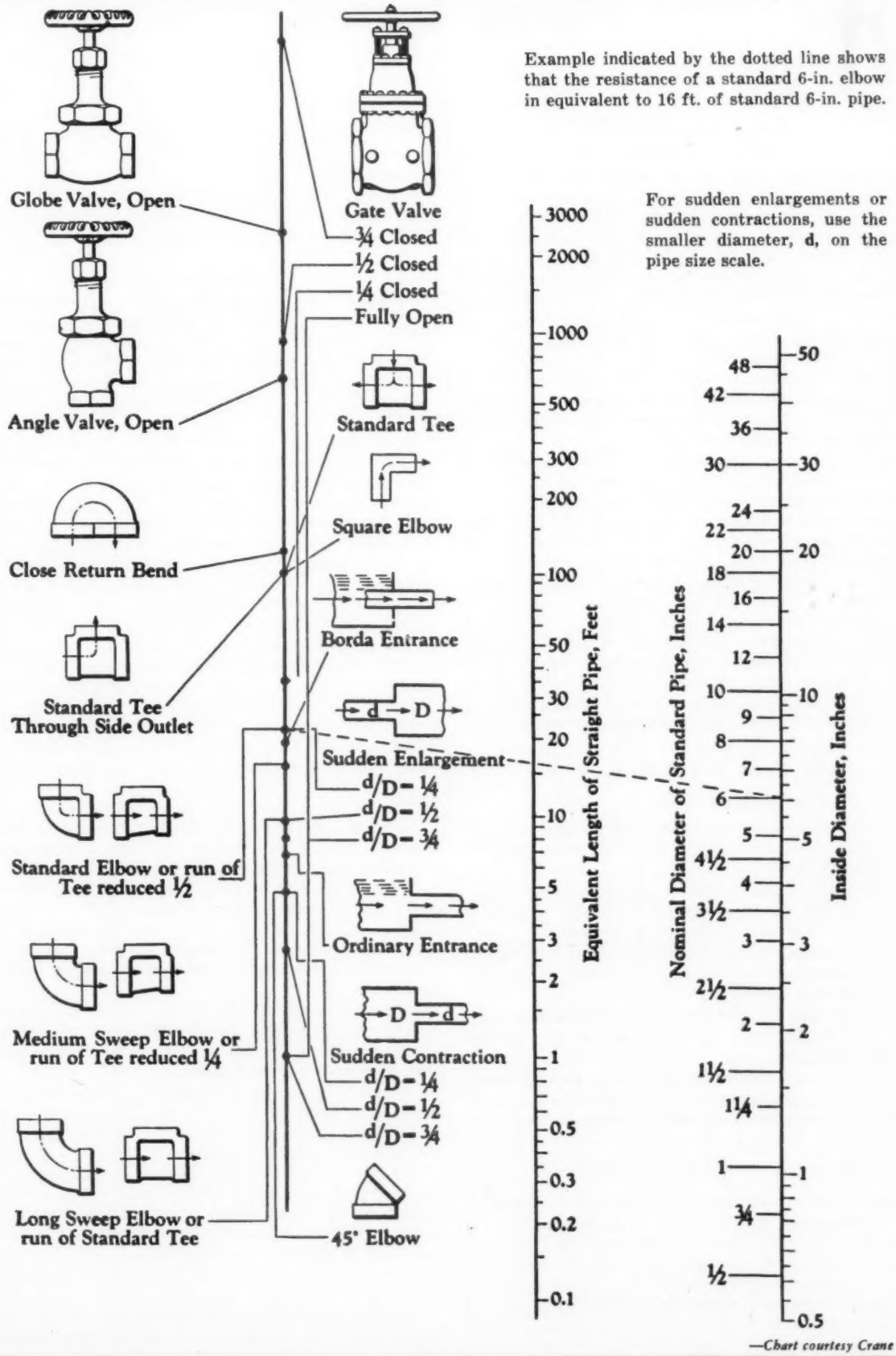
Q = Flow per hour in cubic feet of gas at 14.73 psi absolute (30" Hg.) and 60 F.
P = Pressure drop between pipe terminals in pounds per square inch.
a = Average pressure in pipe line, pounds per square inch absolute. (Absolute initial pressure minus half the pressure drop.)
S = Specific gravity of gas. Air = 1.0.
L = Length of pipe in feet.
d = Internal diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

Values of $\sqrt{d^5}$

Diameter (d) inches (internal)	$\sqrt{d^5}$
.75	.4871
.824 (¾" pipe)	.6163
1.000	1.000
1.049 (1" pipe)	1.127
1.38 (1¼" pipe)	2.237
1.50	2.756
1.61 (1½" pipe)	3.289
2.00	5.657
2.067 (2" pipe)	6.143
2.479 (2½" pipe)	9.579
3.00	15.59
3.068	16.49
4.00	32.00
4.026	32.52
6.00	88.18
8.00	181.0
10.00	316.2
12.00	498.8
16.00	1024.
20.00	1789.
24.00	2822.
30.00	4930.
36.00	7776.

VALVE AND FITTING RESISTANCE TO FLUID FLOW



Example indicated by the dotted line shows that the resistance of a standard 6-in. elbow in equivalent to 16 ft. of standard 6-in. pipe.

For sudden enlargements or sudden contractions, use the smaller diameter, **d**, on the pipe size scale.

—Chart courtesy Crane Co.

Gas Transmission and Distribution Piping Systems

Scope and Intent

804.1 Section 8 of the American Standard Code for Pressure Piping covers the design, fabrication, installation, inspection, testing, and the safety aspects of operation and maintenance of gas transmission and distribution systems, including gas pipe lines, gas compressor stations, gas metering and regulating stations, gas mains, and gas services up to the outlet of the customer's meter set assembly. Also included within the scope of this section are gas storage equipment of the closed pipe type fabricated or forged from pipe or fabricated from pipe and fittings, and gas storage lines.

804.2 The requirements of Section 8 also cover the conditions of use of the elements of the piping systems described in 804.1, including, but not limited to, pipe, valves, fittings, flanges, bolting, gaskets, regulators, pressure vessels, pulsation dampeners, and relief valves.

804.4 The requirements of Section 8 are adequate for safety under conditions normally encountered in the gas industry. Requirements for abnormal or unusual conditions are not specifically provided for, nor are all details of engineering and construction prescribed. It is intended that all work performed within the scope of this section shall meet or exceed the safety standards expressed or implied herein.

804.5 Section 8 is concerned with: (a) Safety of the general public. (b) Employee safety to the extent that it is affected by basic design, quality of the materials and workmanship, and requirements for testing and maintenance of gas transmission and distribution facilities. Existing industrial safety regulations pertaining to work areas, safety devices, and safe work practices are not intended to be supplanted by this code.

ASA Units and Definitions

Pressure Terms

Pressure unless otherwise stated is expressed in pounds per square inch above atmospheric pressure, i.e., gauge pressure. (Abbreviation — psig)

Design pressure is the maximum operating pressure permitted by this code, as determined by the design procedures applicable to the materials and locations involved.

Maximum allowable test pressure is the maximum internal fluid pressure permitted by this code for testing for the materials and locations involved.

Maximum actual operating pressure is the maximum operating pressure existing in a piping system during a normal annual operating cycle.

Maximum allowable operatnig pressure is the maximum pressure at which a piping system may be operated in accordance with the provisions of this code. It is the pressure used in determining the setting of pressure relieving or pressure limiting devices installed to protect the system from accidental over-pressuring.

Standard service pressure is the gas pressure which a utility undertakes to maintain on its domestic customers' meters. (Sometimes called the normal utilization pressure.)

Pressure Control

Pressure relief station consists of equipment installed for the purpose of preventing the pressure on a pipe line or distribution system to which it is connected from exceeding by more than an established increment the maximum allowable operating pressure, by venting gas to the atmosphere whenever the pressure tends to rise too high. (See 805.14 and 845.71.)

Pressure limiting station consists of equipment installed for the purpose of preventing the pressure on a pipe line or distribution system from exceeding the maximum allowable operating pressure, by controlling or restricting the flow of gas when abnormal conditions develop.

Pressure regulating station consists of equipment installed for the purpose of automatically reducing and regulating the pressure in the downstream pipe line or main to which it is connected. Included are piping and auxiliary devices such as valves, control instruments, control lines, the enclosures and ventilating equipment.

Service regulator is a regulator installed on a gas service to control the pressure of the gas delivered to the customer.

Monitoring regulator is a pressure regulator set in series with another pressure regulator for the purpose of automatically taking over in an emergency the control of the pressure downstream of the station in case that pressure tends to exceed a set maximum.

Stress is the resultant internal force that resists change in the size or shape of a body acted on by external forces. In this code "stress" is often used as being synonymous with unit stress which is the stress per unit area (psi).

Operating stress is the stress in a pipe or structural member under normal operating conditions.

Hoop stress is the stress in a pipe wall, acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe and produced by the pressure of the fluid in the pipe.

Maximum allowable hoop stress is the maximum hoop stress permitted by this code for the design of a piping system. It depends upon the material used, the location of the pipe, and the operating conditions.

Secondary stress is stress created in the pipe wall by loads other than internal fluid pressure. For example, backfill loads, traffic loads, beam action in a span, loads at supports and at connections to the pipe.

Nominal wall thickness (t) is the wall thickness computed by the design equation in 841.1. Under this code pipe may be ordered to this computed wall thickness without adding an allowance to compensate for the underthickness tolerances permitted in approved specifications.

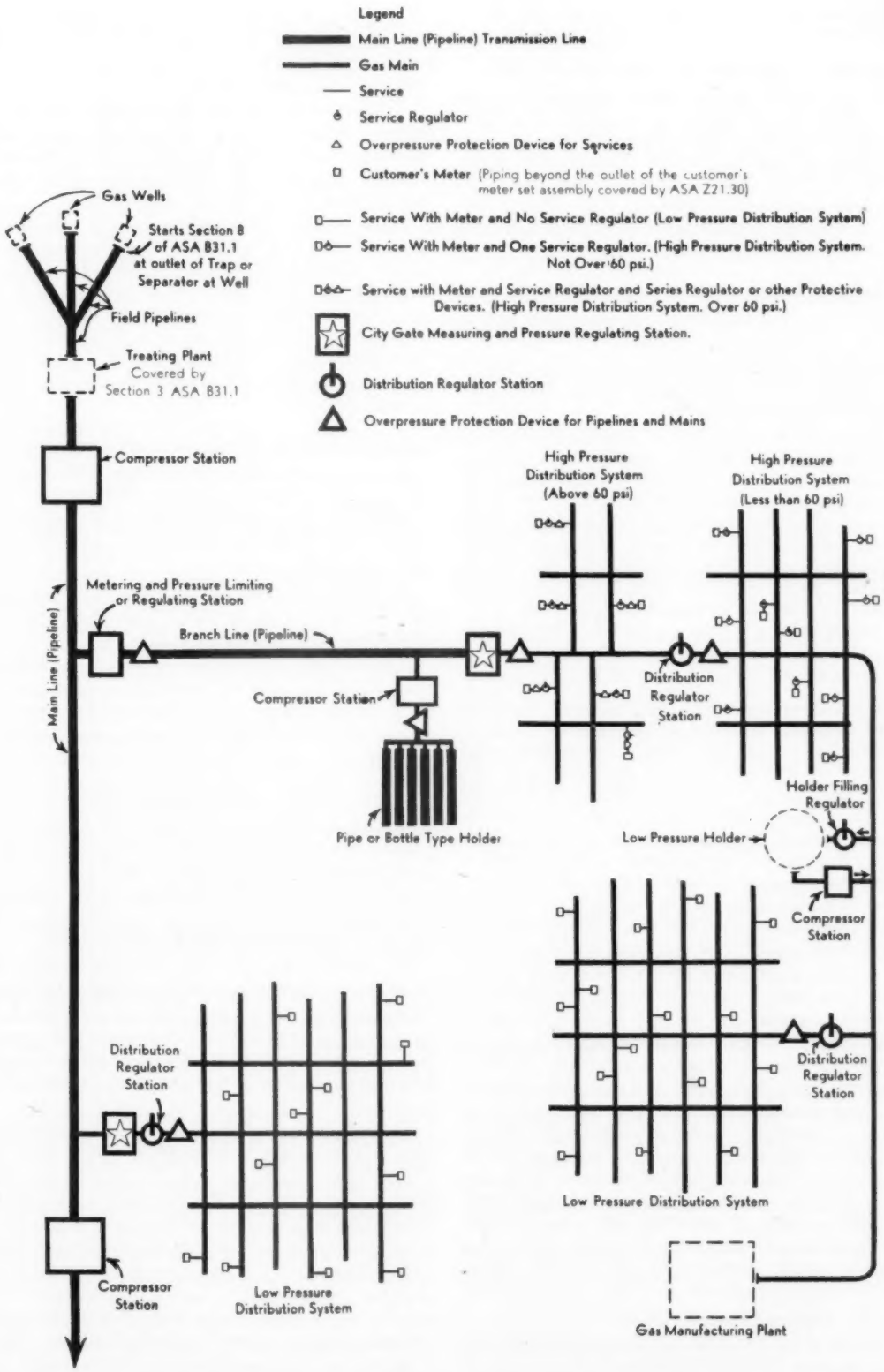
Temperatures are expressed in degrees Fahrenheit (°F.) unless otherwise stated.

Ambient temperature is the temperature of the surrounding medium, usually used to refer to the temperature of the air in which a structure is situated or a device operates.

Pages 46-58 are extracted from American Standard Gas Transmission and Distribution Piping Systems (ASA B31.1.8—1955—Section 8 of American Standard Code for Pressure Piping [ASA B31.1—1955], with the permission of the publishers, The American Society of Mechanical Engineers, 29 West 39th Street, New York 18, New York.)

DIAGRAM SHOWING SCOPE OF SECTION 8 OF ASA B31.1

Facilities indicated by Solid Lines are within the Scope of Section 8 of ASA B31.1


Legend
Main Line (Pipeline) Transmission Line
Gas Main
Service
Service Regulator
Overpressure Protection Device for Services
Customer's Meter (Piping beyond the outlet of the customer's meter set assembly covered by ASA Z21.30)
Service With Meter and No Service Regulator (Low Pressure Distribution System)
Service With Meter and One Service Regulator. (High Pressure Distribution System. Not Over 60 psi.)
Service with Meter and Service Regulator and Series Regulator or other Protective Devices. (High Pressure Distribution System. Over 60 psi.)
City Gate Measuring and Pressure Regulating Station.
Distribution Regulator Station
Overpressure Protection Device for Pipelines and Mains
Gas Wells
Starts Section 8 of ASA B31.1 at outlet of Trap or Separator at Well
Field Pipelines
Treating Plant Covered by Section 3 ASA B31.1
Compressor Station
Main Line (Pipeline)
Metering and Pressure Limiting or Regulating Station
Branch Line (Pipeline)
Compressor Station
Pipe or Bottle Type Holder
High Pressure Distribution System (Above 60 psi)
High Pressure Distribution System (Less than 60 psi)
Distribution Regulator Station
Holder Filling Regulator
Low Pressure Holder
Compressor Station
Distribution Regulator Station
Low Pressure Distribution System
Distribution Regulator Station
Compressor Station
Low Pressure Distribution System
Gas Manufacturing Plant

Ground temperature is the temperature of the earth at pipe depth.

Cold-springing where used in the code is the fabrication of piping to an actual length shorter than its nominal length; and forcing it into position, so that it is stressed in the erected condition; thus compensating partially for the effects produced by the expansion due to an increase in temperature. Cold spring factor is the ratio of the amount of cold spring provided, to the total computed temperature expansion.

Welding, Strength of Materials, and Metallurgical Terms

Yield strength is the strength at which a material exhibits a specified limiting permanent set, or produces a specified total elongation under load. The specified limiting set or elongation is usually expressed as a percentage of gauge length, and its values are specified in the various material specifications acceptable under this code.

Tensile strength is the highest unit tensile stress (referred to the original cross-section) a material can sustain before failure (psi).

Specified minimum yield strength is the minimum yield strength prescribed by the specification under which pipe is purchased from the manufacturer (psi).

Specified minimum tensile strength is the minimum tensile strength prescribed by the specification under which pipe is purchased from the manufacturer (psi).

Specified minimum elongation is the minimum elongation (expressed in per cent of the gauge length) in the tensile test specimen, prescribed by the specifications under which the material is purchased from the manufacturer.

Alloy steel. By common custom steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits:

manganese 1.65%
silicon 60%
copper 60%

or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels:

aluminum
boron
chromium up to 3.99%
cobalt
columbium
molybdenum
nickel
titanium
tungsten
vanadium
zirconium

or any other alloying element added to obtain a desired alloying effect.

Carbon steel. By common custom steel is considered to be carbon steel when no minimum content is specified or required for aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 per cent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

Pipe and Piping Terms

Pipe is a tubular product made as a production item for sale as such. Cylinders formed from plate in the course of the fabrication of auxiliary equipment are not pipe as defined here.

Pipe line or transmission line is a pipe installed for the purpose of transmitting gas from a source or sources of supply to one or more distribution centers or to one or more large volume customers or a pipe installed to interconnect sources of supply. In typical cases pipe lines differ from gas mains in that they operate at higher pressures, they are longer, and the distance between connections is greater.

Gas main or distribution main is a pipe installed in a community to convey gas to individual services or other mains.

Gas service is the pipe that runs between a main or a pipe line and a customer's meter.

Low-pressure distribution system is a gas distribution piping system in which the gas pressure in the mains and services is substantially the same as that delivered to the customer's appliances. In such a system a service regulator is not required on the individual services.

High-pressure distribution system is a gas distribution piping system which operates at a pressure higher than the standard service pressure delivered to the customer. In such a system a service regulator is required on each service to control the pressure delivered to the customer.

Length is a piece of pipe of the length delivered from the mill. Each piece is called a length regardless of its actual dimensions. This is sometimes called "joint" but "length" is preferred.

Cold expanded pipe is seamless or welded pipe which is formed and then expanded in the pipe mill while cold so that the circumference is permanently increased by at least .50 per cent.

Gas storage line is a pipe line used for conveying gas between a compressor station and a gas well used for storing gas underground.

Instrument piping is all piping, valves, and fittings used to connect instruments to main piping, to other instruments and apparatus, or to measuring equipment.

Control piping is all piping, valves, and fittings used to interconnect air, gas, or hydraulically operated control apparatus or instrument transmitters and receivers.

Sample piping is all piping, valves, and fittings used for the collection of samples of gas, steam, water, or oil.

Miscellaneous Terms

Private rights of way as used in this code are rights of way that are not located on roads, streets or highways used by the public, or on railroad rights of way.

Operating company as used here is the individual, partnership, corporation, public agency, or other entity that operates the gas transmission or distribution facilities.

Proprietary items are items made and marketed by a company having the exclusive right to manufacture and sell them.

Location class is a geographic area classified according to its approximate population density and its other characteristics that are considered when prescribing types of construction and methods of testing pipe lines and mains to be located in the area.

Construction type is a construction specification for pipe lines and mains that fixes the stress levels. (See Table 841.02.)

One mile population density index is a number roughly proportional to population density, applicable to a specific 1 mile length of pipe line or main and used in some cases to determine design and/or test requirements. (See 841.001.)

Ten mile population density index is a number roughly proportional to population density, applicable to a specific 10 mile length of pipe line or main and used in some cases to determine design and/or test requirements. (See 841.001.)

Gas as used in this code is any gas or mixture of gases suitable for domestic or industrial fuel and transmitted or distributed to the used through a piping system. The common

types are natural gas, manufactured gas, and liquefied petroleum gas distributed as a vapor with or without the admixture of air.

Miscellaneous Facilities

Customer's meter is a meter which measures gas delivered to a customer for consumption on his premises.

Service shut-off is a valve or cock readily accessible and operable by the customer, located in a service pipe between the gas main and the meter.

Curb shut-off is a buried valve or cock installed in a service pipe at or near the property line and accessible through a valve box and cover and operable by a removable key.

Pipe container is a gas-tight structure assembled in a shop or in the field from pipe and end closures.

Pipe-type holder is any pipe-container or group of interconnected pipe-containers installed at one location, and used for the sole purpose of storing gas.

Bottle as used in this code is a gas-tight structure completely fabricated from pipe with integral drawn, forged, or spun end closures and tested in the manufacturer's plant.

Bottle-type holder is any bottle or group of interconnected bottles installed in one location, and used for the sole purpose of storing gas.

Stop valve is a valve installed for the purpose of stopping the flow of fluid in a pipe.

Hot taps are branch piping connections made to operating pipe lines or mains or other facilities while they are in operation. The connection of the branch piping to the operating line and the tapping of the operating line is done while it is under gas pressure.

Leakage Investigation Terms

Leakage surveys are systematic surveys made for the purpose of locating leaks in a gas piping system. Three types of surveys are referred to in this code and defined below. The significant difference between the three is the manner in which the presence of a leak is first detected. They all involve verification of the presence of a leak and its location, as for example, by the driving or boring of test holes in the vicinity of the leak and testing the atmosphere in these holes with a combustible gas detector or other suitable device.

Vegetation surveys are leakage surveys made for the purpose of finding leaks in underground gas piping by observing vegetation.

Gas detector surveys are leakage surveys made by testing with a combustible gas detector the atmosphere in water meter boxes, street vaults of all types, cracks in pavements and other available locations where access to the soil under pavement is provided.

Bar test surveys are leakage surveys made by driving or boring holes at regular intervals along the route of an underground gas pipe and testing the atmosphere in the holes with a combustible gas detector or other suitable device.

Materials and Equipment

810.1 It is intended that all materials and equipment that will become a permanent part of any piping system constructed under this code shall be suitable and safe for the conditions under which they are used. All such materials and equipment shall be qualified for the conditions of their use by compliance with certain specifications, standards, and special requirements of this code or otherwise as provided herein.

Welding Inspection and Tests

828.1 *Inspection of Welds on Piping Systems Intended to Operate at Less Than 20 per cent of the Specified Minimum Yield Strength.* The quality of welding should be checked visually on a sampling basis, and if there is any reason to believe that the weld is defective, it shall be removed from the line and tested in accordance with the specification or it may be subject to a non-destructive test as outlined in 828.2.

828.2 *Inspection and Tests of Welds on Piping Systems Intended to Operate at 20 per cent or More of the Specified Minimum Yield Strength.*

(a) The quality of welding should be checked by non-destructive tests or by removing completed welds as selected and designated by the operating company. Non-destructive testing may consist of radiographic examination, magnetic particle testing, or other acceptable methods. The tre-panning method of non-destructive testing is prohibited.

(b) When radiographic examination is employed, the procedure set forth in API Standard 1104 (Standard for Field Welding of Pipe Lines) shall be followed; and the number and location of welds examined shall be at the discretion of the operating company.

(c) Completed welds which have been removed for inspection shall, to be acceptable, successfully meet the testing requirements outlined under the welder qualification procedure, and in addition, shall meet the standards of acceptability contained in 829.

829 *Standards of Acceptability of Welds on Pipe Lines Intended to Operate at 20 per cent or More of the Specified Minimum Yield Strength.* (These requirements are identical with the requirements of API 1104.)

829.1 *Inadequate Penetration and Incomplete Fusion.* Any individual inadequate penetration or incomplete fusion shall not exceed 1 inch in length. In any 12-inch length of weld, the total length of inadequate penetration or incomplete fusion shall not exceed 1 inch. The total length of the inadequate penetration or incomplete fusion in any two succeeding 12-inch lengths shall not exceed 2 inches and individual defects shall be separated by at least 6 inches of sound weld metal.

829.2. *Burn-Through Areas.* Any individual burn-through area shall not exceed ¾ inch in length. In any 12-inch length of weld, the total length of burn-through area shall not exceed 1-1½ inches. The total length of burn-through area in any two succeeding 12-inch lengths shall not exceed 3 inches, and individual defects shall be separated by at least 6 inches of sound weld metal.

829.3 *Elongated Slag Inclusions.* Any elongated slag inclusion shall not exceed 2 inches in length or 1/16 inch in width. In any 12-inch length of weld, the total length of elongated slag inclusions shall not exceed 2 inches. The total length of elongated slag inclusions in any two succeeding 12-inch lengths, shall not exceed 4 inches, and individual defects shall be separated by at least 6 inches of sound weld metal. Parallel slag lines shall be considered as individual defects if they are wider than 1/32 inch.

829.4 *Isolated Slag Inclusions.* The maximum width of any isolated slag inclusion shall not exceed ⅛ inch. In any 12-inch length of weld, the total length of isolated slag inclusions shall not exceed 1 inch, nor shall there be more than four isolated slag inclusions of the maximum width of ⅛ inch in this length. Any two such inclusions shall be separated by 2 inches of sound weld metal. In any 24-inch length of weld, the total length of isolated slag inclusions shall not exceed 2 inches.

829.5 *Gas Pockets.* The maximum dimensions of any individual gas pocket shall not exceed ⅛ inch. Maximum distribution of gas pockets shall not exceed that shown in Figures 3 and 4 of API Standard 1104.

829.6 *Cracks.* No welds containing cracks, regardless of size or location shall be acceptable until such welds have been repaired in conformance with 829.9.

829.7 *Accumulation of Discontinuities.* Any accumulation of discontinuities having a total length of more than 2

inches in a weld length of 12 inches is unacceptable. Any accumulation of discontinuities which total more than 10 per cent of the weld length of a joint is unacceptable.

829.8 *Undercutting.* Undercutting adjacent to the cover bead on the outside of the pipe shall not exceed 1/32 inch in depth and 2 inches in length. Undercutting adjacent to the root bead on the inside of the pipe shall not exceed 2 inches in length.

829.9 *Repair of Defects.*

(a) Except as provided in (g) below, defective welds shall be repaired or removed from the pipe line at the request of the company representative. The company may authorize repairs of defects in the root and filler beads, but any weld that shows evidence of repair work having been done without authorization by the company may be rejected.

(b) Minor cracks in the surface and filler beads may be repaired when so authorized by the company, but any crack penetrating the root bead or the second bead shall be cause for complete rejection of the weld. The entire weld shall be cut from the pipe line and replaced. Minor cracks shall be defined as cracks visible in the surface bead and not over 2 inches in length.

(c) Before repairs are made, injurious defects shall be removed by chipping, grinding, or oxygen gouging to clean metal. All slag and scale shall be removed by wire brushing.

(d) It is recommended that all such areas be preheated before the repair weld is started.

(e) Repaired areas shall be carefully inspected and radiographed when considered necessary.

(f) No further repairs shall be allowed in repaired areas.

(g) Repairs may be made to pin holes and undercuts in the final bead without authorization, but must meet with the approval of the company.

Piping System Components

831 All components of piping systems, including valves, flanges, fittings, headers, special assemblies, etc., shall be designed to withstand operating pressures, and other specified loadings, with unit stresses not in excess of those permitted for comparable material in pipe in the same location and type of service. Components shall be selected that are designed to withstand the field test pressure to which they will be subjected, without failure or leakage, and without impairment of their serviceability.

Design, Installation, and Testing

840.1 *General Provisions.* The design requirements of the code are intended to be adequate for public safety under all conditions usually encountered in the gas industry. However, special conditions that may cause additional stress in any part of a line or its appurtenances shall be provided for, using good engineering practice. Examples of such special conditions include: long self-supported spans, unstable ground, mechanical or sonic vibrations, weight of special attachments, and thermal forces other than seasonal.

Steel Pipe

841.001 *Population Density Indices*

(a) Two population density indices, determined at the time of initial construction, are used to classify locations for design and testing purposes: (1) the one-mile density index, which applies to any specific mile of pipe line; and (2) the ten-mile density index, which applies to any specific ten-mile length of pipe line.

(b) To determine the one-mile density indices for a proposed pipe line, lay out a zone one-half mile wide along the route of the pipe line with the pipe line on the center line of this zone. Divide the zone into lengths, each containing one mile of pipe line. Count the number of buildings intended for human occupancy in each of these lengths. These numbers are the one-mile indices for the pipe line.

(c) To determine the ten-mile density indices for any given ten-mile length of pipe line, proceed as follows: Add the one-mile density indices for the ten-mile section. In case a one-mile index equals or exceeds 20, it is to be included in the sum as 20. Divide the sum thus obtained by 10. The quotient is the ten-mile density index for the section.

Classification of Locations

841.011 *Class 1 Locations.* Class 1 locations include waste lands, deserts, rugged mountains, grazing land, and farm land, and combinations of these; provided, however, that:

(a) The ten-mile density index for any section of the line is 12 or less.

(b) The one-mile density index for any one mile of line is 20 or less. See Note (1).

841.012 *Class 2 Locations.* Class 2 locations include areas where the degree of development is intermediate between Class 1 locations and Class 3 locations. Fringe areas around cities and towns, and farm or industrial areas where the one-mile density index exceeds 20 or the ten-mile density index exceeds 12 fall within this location class.

Note (1): It is not intended that a full mile of lower-stress-level pipe line shall be installed if there are physical barriers or other factors that will limit the further expansion of the more densely populated area to a total distance of less than 1 mile. It is intended, however, that where no such barriers exist, ample allowance shall be made in determining the limits of the lower-stress design to provide for probable further development in the area.

841.013 *Class 3 Locations.* Class 3 locations include areas subdivided for residential or commercial purposes where, at the time of construction of the pipe line or piping system, 10 per cent or more of the lots abutting on the street or right-of-way in which the pipe is to be located are built upon, and a Class 4 classification is not called for. This permits classifying as Class 3, areas completely occupied by commercial or residential buildings with the prevalent height of three stories or less.

841.014 *Class 4 Locations.* Class 4 locations include areas where multistory[1] buildings are prevalent, and where traffic is heavy or dense and where there may be numerous other utilities underground.

841.015 It should be emphasized that *Location Class* (1, 2, 3 or 4), as described in the foregoing paragraphs, is defined as the general description of a geographic area having certain characteristics as a basis for prescribing the types of construction and methods of testing to be used in those locations or in areas that are respectively comparable. A numbered Location-Class refers only to the geography of that location or a similar area, and does not necessarily indicate that a correspondingly numbered Construction-Type will suffice for all construction in that particular location or area. Example: In Locating Class 1, all aerial crossings require Type B construction. (See 841.143)

841.016 When classifying locations for the purpose of determining the type of pipe line construction and testing that should be prescribed, due consideration shall be given to the possibility of future development of the area. If at the time of planning a new pipe line this future development appears likely to be sufficient to change the location class, this should be taken into consideration in the design and testing of the proposed pipe line.

It is also anticipated that some increase in population density will occur in all areas after a line is constructed, and this possibility has been taken into account in establishing the design, construction, and testing procedures for each location class.

Note (1): Multistory means 4 or more "floors" above ground including the first or ground floor. The depth of basements or number of basement floors is immaterial.

841.1 *Steel Pipe Design Formula.* The design pressure for steel piping systems or the normal wall thickness for a given design pressure shall be determined by the following formula:

$$P = \frac{2St}{D} \times F \times E \times T$$

(For exceptions see 841.4)

Where:

P = Design pressure, psig

S = Specified minimum yield strength, psi, stipulated in the specifications under which the pipe was purchased from the manufacturer or determined in accordance with 811.27 H. The specified minimum yield strengths of some of the more commonly used piping steels, whose specifications are incorporated by reference herein, are tabulated for convenience in Appendix "C". For special limitation on S see 841.14 (e) and (f).

D = Nominal outside diameter of pipe, inches.

t = Nominal wall thickness, inches.

F = Construction type design factor obtained from 841.11.

E = Longitudinal joint factor obtained from 841.12.

T = Temperature derating factor obtained from Table 841.13.

Table 841.11
Values of Design Factor "F"

Construction Type (See 841.02)	*Design Factor F*
Type — A	0.72
Type — B	0.60
Type — C	0.50
Type — D	0.40

Table*841.12
Longitudinal Joint Factor "E"

Spec. Number	*Pipe Type*	*E Factor*
ASTM A53	Seamless	1.00
	Electric Resistance Welded	1.00
	Furnace Lap Welded	.80
	Furnace Butt Welded	.60
ASTM A106	Seamless	1.00
ASTM A134	Electric Fusion Welded	.80
ASTM A135	Electric Resistance Welded	1.00
ASTM A139	Electric Fusion Welded	.80
ASTM A155	Electric Fusion Welded	1.00
API 5L	Seamless	1.00
	Electric Resistance Welded	1.00
	Electric Flash Welded	1.00
	Furnace Lap Welded	.80
	Furnace Butt Welded	.60
API 5LX	Seamless	1.00
	Electric Resistance Welded	1.00
	Electric Flash Welded	1.00
	Submerged Arc Welded	1.00

Table 841.13
Temperature Derating Factor "T" For Steel Pipe

Temperature Degrees Fahrenheit	*Temperature Derating Factor "T"*
200° F. or less	1.000
300° F.	0.967
350° F.	0.933
400° F.	0.900
450° F.	0.867

NOTE: For intermediate temperatures interpolate for derating factor.

CLASSIFICATION OF STEEL PIPE CONSTRUCTION[1]

Four types of steel pipe construction are prescribed in this code. The distinguishing characteristics of each type and the locations in which each type shall be used are as follows:

A. Characteristics	Type A construction	Type B construction	Type C construction	Type D construction
1. Design Factor F (See 841.11)	.72	.60	.50	.40
B. Locations where type of construction shall be used.	(a) On private rights of way in class I locations. (b) Parallel encroachments on: Privately owned roads in class 1 locations. Unimproved roads in class 1 locations. (c) Crossings without casings of privately owned roads in class 1 locations. (d) Crossings in casings of unimproved public roads hard-surfaced roads highways or public streets and railroads in class 1 locations.	(a) On private rights of way in class 2 locations. (b) Parallel encroachments on: Privately owned roads in class 2 locations. Unimproved public roads in class 2 locations. Hard surfaced roads, highways or public streets and railroads in class 1 locations. (c) Crossings without casings of: Privately owned roads in class 2 locations. Unimproved public roads in class 2 locations. Hard surfaced roads, highways or public streets and railroads in class 1 and class 2 locations. (d) Crossings in casings of: Hard surfaced roads, highways or public streets and railroads in class 2 locations. (e) On bridges in class 1 and class 2 locations. (See 841.143) (f) Fabricated assemblies in pipe lines in location classes 1 and 2. (See 841.142)	(a) On private rights of way in class 3 locations. (b) Parallel encroachments on: Privately owned roads in class 3 locations. Unimproved public roads in class 3 locations. Hard surfaced roads, highways or public streets and railroads in class 3 locations. (c) Crossings without casings of: Privately owned roads in class 3 locations. Unimproved public roads in class 3 locations. Hard surfaced roads, highways or public streets and railroads in class 2 and 3 locations. (d) Compressor station piping.	(a) In all locations in location class 4.

(1) It is necessary to distinguish between construction types, as defined by Section A of this table, and location classes, as defined in 841.01, to avoid confusion. If pipelines or mains are located in private rights of way, the code prescribes that Type A construction be used in Class 1 locations, Type B construction in Class 2 locations, Type C construction in Class 3 locations, and Type D construction in Class 4 locations. There are many exceptions to this association of Class 1 with Type A, etc., however, as Table 841.02 shows, most of which are cases where pipelines or mains are located in highways or on bridges, etc.

CONSTRUCTION TYPES REQUIRED FOR PARALLEL ENCROACHMENTS OF PIPELINES AND MAINS ON ROADS AND RAILROADS

Kind of Thoroughfare	Construction Type Required			
	Location class 1	Location class 2	Location class 3	Location class 4
(a) Privately owned roads	Type A	Type B	Type C	Type D
(b) Unimproved public roads	Type A	Type B	Type C	Type D
(c) Hard surface roads, highways or public streets and railroads	Type B	Type B	Type C	Type D

CONSTRUCTION TYPES REQUIRED FOR PIPELINES AND MAINS CROSSING ROADS AND RAILROADS

Kind of Thoroughfare	Construction Type Required			
	Location class 1	Location class 2	Location class 3	Location class 4
(a) Privately owned roads	Type A without casing	Type B without casing	Type C without casing	Type D without casing
(b) Unimproved public roads	Type A with casing Type B without casing	Type B without casing	Type C without casing	Type D without casing
(c) Hard surface roads, highways or public streets and railroads	Type A with casing Type B without casing	Type B with casing Type C without casing	Type C without casing	Type D without casing

STANDARD THICKNESSES OF CAST IRON PIT CAST PIPE FOR GAS

THICKNESS IN INCHES. WORKING PRESSURE IN POUNDS PER SQUARE INCH.
THICKNESSES INCLUDE ALLOWANCES FOR FOUNDRY PRACTICE AND CORROSION
Laying Condition A — Flat Bottom Trench, Without Blocks, Untamped Backfill
Laying Condition B — Flat Bottom Trench, Without Blocks, Tamped Backfill
Laying Condition C — Pipe Laid on Blocks, Untamped Backfill
Laying Condition D — Pipe Laid on Blocks, Tamped Backfill

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
4	10	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.46	.40
	50	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.50	.40
	100	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
	150	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
6	10	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.54	.43
	50	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.54	.43
	100	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.58	.43
	150	.43	.43	.50	.43	.43	.43	.50	.43	.43	.43	.58	.43
8	10	.46	.46	.50	.46	.46	.46	.54	.46	.46	.46	.58	.46
	50	.46	.46	.54	.46	.46	.46	.54	.46	.46	.46	.63	.46
	100	.46	.46	.54	.46	.46	.46	.58	.46	.46	.46	.63	.46
	150	.46	.46	.54	.46	.46	.46	.58	.46	.46	.46	.63	.46
10	10	.50	.50	.54	.50	.50	.50	.58	.50	.50	.50	.68	.50
	50	.50	.50	.58	.50	.50	.50	.58	.50	.50	.50	.68	.54
	100	.50	.50	.58	.50	.50	.50	.63	.50	.54	.50	.68	.54
	150	.50	.50	.58	.50	.50	.50	.63	.50	.54	.50	.68	.58
12	10	.54	.54	.58	.54	.54	.54	.63	.54	.54	.54	.68	.58
	50	.54	.54	.58	.54	.54	.54	.63	.54	.58	.54	.73	.58
	100	.54	.54	.63	.54	.54	.54	.63	.54	.58	.58	.73	.58
	150	.54	.54	.63	.58	.58	.54	.68	.58	.63	.58	.79	.63
16	10	.58	.58	.68	.58	.58	.58	.68	.63	.68	.63	.79	.68
	50	.58	.58	.68	.63	.63	.58	.73	.63	.68	.63	.79	.73
	100	.63	.58	.73	.63	.63	.58	.73	.68	.73	.68	.85	.73
20	10	.66	.66	.77	.71	.71	.66	.83	.71	.77	.71	.90	.83
	50	.71	.66	.77	.71	.71	.66	.83	.77	.77	.71	.90	.83
	100	.71	.66	.83	.77	.77	.71	.83	.77	.83	.77	.97	.83
24	10	.74	.74	.80	.74	.80	.74	.86	.80	.86	.80	.93	.86
	50	.80	.74	.86	.80	.80	.74	.93	.86	.86	.80	1.00	.93
	100	.80	.74	.93	.86	.86	.80	.93	.86	.93	.86	1.00	.93
30	10	.87	.87	.94	.87	.94	.87	1.02	.94	1.02	.87	1.10	1.02
	50	.94	.87	1.02	.94	.94	.87	1.10	1.02	1.10	.94	1.19	1.10
36	10	1.05	.97	1.05	.97	1.05	.97	1.13	1.05	1.13	.97	1.22	1.13
	50	1.05	.97	1.13	1.05	1.13	.97	1.22	1.13	1.22	1.05	1.32	1.22
42	10	1.16	1.07	1.16	1.07	1.16	1.07	1.25	1.16	1.35	1.07	1.35	1.25
	50	1.16	1.07	1.25	1.16	1.25	1.07	1.35	1.25	1.35	1.16	1.46	1.35
48	10	1.27	1.18	1.37	1.18	1.37	1.18	1.37	1.27	1.48	1.18	1.60	1.37
	50	1.27	1.18	1.37	1.27	1.37	1.18	1.48	1.37	1.48	1.27	1.60	1.48

NOTE: This table is taken from ASA A21.3

STANDARD THICKNESS OF CAST IRON GAS PIPE CENTRIFUGALLY CAST IN METAL MOLDS OR SAND LINED MOLDS

THICKNESS IN INCHES. WORKING PRESSURE IN POUNDS PER SQUARE INCH.
THICKNESSES INCLUDE ALLOWANCES FOR FOUNDRY PRACTICE AND CORROSION
Laying Condition A — Flat Bottom Trench, Without Blocks, Untamped Backfill
Laying Condition B — Flat Bottom Trench, Without Blocks, Tamped Backfill
Laying Condition C — Pipe Laid on Blocks, Untamped Backfill
Laying Condition D — Pipe Laid on Blocks, Tamped Backfill

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
4	10	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	50	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	100	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	150	.35[1]	.35	.35	.35	.35	.35	.38	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
6	10	.38[1]	.38	.41	.38	.38	.38	.41	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.41	.41	.41	.41	.48	.41
	50	.38[1]	.38	.41	.38	.38	.38	.41	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.41	.41	.41	.41	.48	.41
	100	.38[1]	.38	.41	.38	.38	.38	.44	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.44	.41	.41	.41	.48	.41
	150	.38[1]	.38	.41	.38	.38	.38	.44	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.44	.41	.41	.41	.48	.41
8	10	.41	.41	.44	.41	.41	.41	.48	.41	.41	.41	.52	.41
	50	.41	.41	.44	.41	.41	.41	.48	.41	.41	.41	.52	.41
	100	.41	.41	.48	.41	.41	.41	.48	.41	.41	.41	.56	.41
	150	.41	.41	.48	.41	.41	.41	.48	.41	.41	.41	.56	.41
10	10	.44	.44	.48	.44	.44	.44	.52	.44	.44	.44	.60	.44
	50	.44	.44	.48	.44	.44	.44	.52	.44	.44	.44	.60	.44
	100	.44	.44	.52	.44	.44	.44	.52	.44	.44	.44	.60	.48
	150	.44	.44	.52	.44	.44	.44	.56	.44	.48	.44	.60	.48
12	10	.48	.48	.52	.48	.48	.48	.56	.48	.48	.48	.60	.52
	50	.48	.48	.52	.48	.48	.48	.56	.48	.48	.48	.60	.52
	100	.48	.48	.56	.48	.48	.48	.56	.48	.52	.48	.65	.52
	150	.48	.48	.56	.48	.48	.48	.56	.48	.52	.48	.65	.52
16	10	.54	.50	.58	.54	.54	.50	.63	.58	.58	.54	.73	.63
	50	.54	.50	.63	.54	.54	.50	.63	.58	.63	.58	.73	.63
	100	.54	.54	.63	.58	.58	.54	.68	.58	.63	.58	.73	.68
20	10	.62	.57	.67	.62	.62	.57	.72	.67	.67	.62	.78	.72
	50	.62	.57	.72	.62	.67	.57	.72	.67	.72	.62	.78	.72
	100	.62	.57	.72	.67	.67	.62	.78	.67	.72	.67	.84	.78
24	10	.68	.63	.73	.68	.73	.63	.79	.73	.79	.68	.85	.79
	50	.68	.63	.79	.68	.73	.63	.79	.73	.79	.73	.85	.79
	100	.73	.63	.79	.73	.73	.68	.85	.79	.79	.73	.92	.85
30	10	.79	.73	.85	.79	.85	.73	.92	.85	.92	.79	.99	.92
	50	.85	.73	.85	.85	.85	.79	.92	.85	.92	.85	.99	.92
36	10	.87	.81	.94	.87	.94	.81	1.02	.94	1.02	.87	1.10	1.02
	50	.94	.81	1.02	.94	1.02	.87	1.10	.94	1.10	.94	1.19	1.02
42	10	1.05	.90	1.05	.97	1.05	.90	1.13	1.05	1.13	.97	1.22	1.13
	50	1.05	.90	1.13	1.05	1.13	.97	1.13	1.05	1.22	1.05	1.32	1.13
48	10	1.14	.98	1.14	1.06	1.14	.98	1.23	1.14	1.33	1.06	1.33	1.23
	50	1.14	.98	1.23	1.14	1.23	1.06	1.33	1.14	1.33	1.14	1.44	1.33

[1]Class 22 Thickness.
[2]Class 23 Thickness offers increased factor of safety and is recommended for use in areas of dense population and heavy traffic.

NOTE: This table is taken from ASA A21.7 and A21.9

Operating and Maintenance Procedures

850 **Operating and Maintenance Procedures affecting the safety of gas transmission and distribution facilities**

850.1 Because of many variables, it is not possible to prescribe in a national code a set of operating and maintenance procedures that will be adequate from the standpoint of public safety in all cases without being burdensome and impractical in some.

850.2 It is possible, however, for each operating company to develop operating and maintenance procedures based on experience, knowledge of its facilities and conditions under which they are operated, which will be entirely adequate from the standpoint of public safety.

850.3 **Basic Requirement.** Each operating company having gas transmission or distribution facilities within the scope of this code shall:

(a) Have a plan covering operating and maintenance procedures in accordance with the purpose of this code.

(b) Operate and maintain its facilities in conformance with this plan.

(c) Keep records necessary to administer the plan properly.

(d) Modify the plan from time to time as experience with it dictates and as exposure of the public to the facilities and changes in operating conditions require.

850.4 **Essential Features of the Plan.** The plan prescribed in 850.3 (a) above should include:

(a) Detailed plans and instructions to employees covering operating and maintenance procedures for gas facilities during normal operations and repairs, and during emergencies.

(b) Items recommended for inclusion in the plan for specific classes of facilities are given in 851 to 857, inclusive.

(c) Particular attention should be given to those portions of the facilities presenting the greatest hazard to the public in the event of an emergency or because of construction or extraordinary maintenance requirements.

852 **Distribution Piping Maintenance**

852.1 **Patrolling.** Distribution mains, which are installed in locations or on structures where abnormal physical movement or abnormal external loading could cause failure or leakage, shall be patrolled periodically and the frequency of the patrolling shall be determined by the severity of the conditions which could cause failure or leakage and the consequent hazards to public safety.

852.2 **Leakage Surveys and Routine Procedures**

852.21 Each operating company having a gas distribution system shall set up in its operating and maintenance plan a provision for the making of periodic leakage surveys. The types of surveys prescribed in the plan shall be one or more of the following employed singly or in combination, or some other effective procedure for locating leaks in underground piping systems.

(a) Gas detector surveys.

(b) Bar test surveys.

(c) Vegetation surveys.

(d) Pressure drop surveys.

(e) Soapsuds testing on exposed pipe and fittings.

852.22 The nature of the operations and local conditions of each individual company shall determine the type and scope of the leakage control program most suitable. The character of the general service area together with housing concentration should determine the frequency of the inspection program.

It is recommended that the inspection program should include at least the following provisions:

(a) At least once a year a gas detector survey should be conducted in business districts, involving tests of the atmosphere in gas, electric, telephone, sewer and water system manholes, at cracks in pavement and sidewalks and at other locations providing an opportunity for finding gas leaks. Leakage surveys, using one or more of the types referred to in 852.21, should be made of the distribution system outside of the principal business areas as frequently as experience indicates that they are necessary but not less than once every five years.

(b) Leaks located by these surveys shall be investigated promptly and any necessary repairs shall be made. When the condition of a main or a service, as indicated by leak frequency records or visual observation, deteriorates to the point where it should not be retained in service, it should be replaced or reconditioned.

852.3 **Abandoning Inactive Service and Mains**

Each operating company shall have a plan in its operation and maintenance procedures for sealing off the supply of gas to all abandoned services and mains by means of valves or other effective methods. This plan shall include procedures for abandoning services that have remained inactive for a period of years and for which there is no planned use. It is recommended that the plan include the following provisions:

854 **Procedures for Maintaining Pipe-Type and Bottle-Type Holders in Safe Operating Condition**

854.1 Each operating company having a pipe-type or bottle-type holder shall prepare and place in its files a plan for the systematic, routine inspection and testing of the facilities which provides that:

854.11 Procedures shall be followed to enable the detection of external corrosion before the strength of the container has been impaired.

854.12 Periodic sampling and testing of gas in storage will

be made to determine the dew point of vapors contained in the stored gas that might cause internal corrosion or interfere with the safe operations of the storage plant.

854.13 The pressure control and pressure limiting equipment will be inspected and tested periodically to see if it is in a safe operating condition and has adequate capacity.

854.2 Each operating company, having prepared such a plan as described in 854.1 above, shall follow the plan, and keep records which detail the inspection and testing work done and the conditions found.

854.3 All unsatisfactory conditions found shall be promptly corrected.

855 **Maintenance of Pressure Limiting and Pressure Regulating Stations**

855.1. All pressure limiting stations, relief devices, and pressure regulating stations and equipment shall be subjected to systematic periodic inspections and/or tests to determine that they are:

(a) In good mechanical condition.

(b) Adequate from the standpoint of capacity and reliability of operation for the service in which they are employed.

(c) Set to function at the correct pressure.

(d) Properly installed and protected from dirt, liquids, or other conditions that might prevent proper opeation.

855.2 (a) Every distribution system supplied by more than one district pressure regulating station shall be equipped with telemetering or recording pressure gauges to indicate the gas pressure in the district.

(b) On distribution systems supplied by a single district pressure regulating station the operating company shall determine the necessity of installing such gauges in the district. In making this determination the operating company shall take into consideration the operating conditions such as the number of customers supplied, the operating pressures, and the capacity of the installation, etc.

(c) If there are indications of abnormal high or low pressure the regulator and the auxiliary equipment shall be inspected and the necessary measures shall be employed to rectify any unsatisfactory operating conditions. Suitable periodic inspections of single district pressure regulation stations not equipped with telemetering or recording gauges shall be made to determine that the pressure regulating equipment is functioning properly.

855.3 Whenever it is practicable to do so, pressure relief valves should be tested in place to determine that they have sufficient capacity to limit the pressure on the facilities to which they are connected to the desired maximum pressure. If such tests are not feasible, periodic review and calculation of the required capacity of the relieving equipment at each station should be made and these required capacities compared with the rated or experimentally determined relieving capacity of the installed equipment for the operating conditions under which it works. If it is determined that the relieving equipment is of insufficient capacity, steps shall be taken to install new or additional equipment to provide capacity.

856 **Valve Maintenance**

856.1 **Pipeline Valves** that might be required during an emergency shall be inspected periodically and partially operated at least once per year to provide safe and proper operating conditions.

856.2 **Distribution System Valves.** Valves, the use of which may be necessary for the safe operation of a gas distribution system, shall be checked and serviced, including lubrication where necessary, at sufficiently frequent intervals to be reasonably assured of their satisfactory operation. Inspection shall include checking of alignment to permit use of a key or wrench and clearing from the valve box or vault any debris which would interfere with or delay the operation of the valve.

857 **Vault Maintenance.** Regularly scheduled inspections shall be made of each vault housing pressure regulating and pressure limiting equipment and having a volumetric internal content of 200 cubic feet or more to determine if it is in good physical condition and adequately vented. This inspection shall include the testing of the atmosphere in the vault atmosphere, the equipment in the vault shall be inspected for leaks and leaks found shall be repaired. The ventilating equipment shall also be inspected to determine if it is functioning properly. If the ventilating ducts are obstructed, they shall be cleared. The condition of the vault covers shall be carefully examined to see that they do not present a hazard to public safety.

Miscellaneous

860 **Miscellaneous**

861 **Odorization.** Any gas, distributed to consumers through gas mains or gas services or used for domestic purposes in compressor plants, which does not naturally possess a distinctive odor to the extent that its presence in the atmosphere is readily detectable at concentrations well below that required to produce an explosive mixture shall have an odorant added to it to make it so detectable. Odorization is not necessary, however, for such gas as is delivered for further processing or use where the odorant would serve no useful purpose as a warning agent.

862 **Liquefied Petroleum Gas (LPG) Systems.**

862.1 Liquefied petroleum gases, generally, include butane and propane, and mixtures of them that can be stored as liquids under moderate pressures (approximately 80 psig to 250 psig) at ambient temperatures.

862. This code is concerned only with certain safety aspects of liquefied petroleum gases when they are vaporized and used as gaseous fuels.

862.3 All of the requirements of Standards No. 58 and No. 59 of the National Board of Fire Underwriters and the National Fire Protection Association and of this code, concerning design, construction, and operation and maintenance of piping facilities shall apply to piping systems handling butane, propane, or mixtures of these gases.

862.4 **Special Safety Requirements for LPG Systems**

862.41 **Odorization.** Liquefied petroleum gases are usually nontoxic, but for safety when distributed for consumer use, or used as fuel in a place of employment, they shall be odorized. Criteria for odorization are given in 861. See note (1)

862.42 **Ventilation**

(a) All liquefied petroleum gases are heavier than air, hence structures above ground for housing regulators, meters, etc., shall have open vents near the floor level. Such equipment shall not be installed in pits or in underground vaults, except in cases where suitable provisions for forced ventilation are made.

(b) Special care is required in the location of relief valve discharge vents releasing LPG to the atmosphere, to prevent accumulation of the heavy gases at or below ground level. Likewise, special precautions are necessary for adequate ventilation where excavations are made for the repair of leaks in an underground LPG distribution system.

863 **Pipelines on Private Right-of-Way of Electric Transmission Lines.**

Where gas pipelines parallel overhead electric transmission lines on the same right of way, the company operating the pipelines shall take the following precautions:

863.1 Employ blow-out connections that will direct the gas away from the electric conductors.

863.2 Install a bonding conductor across points where the main is to be separated and maintain this connection while the pipeline is separated. The current carrying capacity of the bonding conductor should be at least one-half of the capacity of the overhead line conductors.

Note: (1) Refer to National Board of Fire Underwriters and the National Fire Protection Association Bulletins No. 58 — Storage and Handling of Liquified Petroleum Gases, and No. 59 — Liquified Petroleum Gases at Utility Gas Plants

863.3 Make a study in collaboration with the electric company on the common problems of corrosion and electrolysis, taking the following factors into consideration:

(a) The possibility of the pipeline carrying either unbalanced line currents or fault currents.

(b) The possibility of lightning or fault currents inducing voltages sufficient to puncture pipe coating or pipe.

(c) Cathodic protection of the pipeline, including location of ground beds, especially if the electric line is carried on steel towers.

(d) Desirability of installing electric bonding connections between the pipeline and either the steel tower footings or the buried ground facilities or the ground-wire of the overhead electric system.

863.4 Investigate the necessity of protecting insulating joints in the pipeline against induced voltages or currents resulting from lightning strokes. Such protection can be obtained by connecting buried sacrificial anodes to the pipe near the insulating joints or by bridging the pipeline insulator with a spark-gap or by other effective means.

API Specifications for Line Pipe

STANDARD-WEIGHT THREADED LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7	8	9	10	11	12
					Calculated Weight, lb. per ft.			Test Pressure, psi., min.			
								Steel			Iron
Size: Nominal, in.	Outside Diameter, in. D	Nominal Weight:[1] Threads and Coupling, lb. per ft.	Wall Thickness[2], in. t	Inside Diameter[2], in. d	Plain End w_{pe}	Threads and Coupling[1] w	Calculated Coupling Weight, lb.	Butt-Welded	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[3]
⅛	0.405	0.25	0.068	0.269	0.24	0.25	0.04	700	700	700	700
¼	0.540	0.43	0.088	0.364	0.42	0.43	0.09	700	700	700	700
⅜	0.675	0.57	0.091	0.493	0.57	0.57	0.13	700	700	700	700
½	0.840	0.86	0.109	0.622	0.85	0.86	0.24	700	700	700	700
¾	1.050	1.14	0.113	0.824	1.13	1.14	0.34	700	700	700	700
1	1.315	1.70	0.133	1.049	1.68	1.69	0.54	700	700	700	700
1¼	1.660	2.30	0.140	1.380	2.27	2.30	1.03	800	1000	1100	800
1½	1.900	2.75	0.145	1.610	2.72	2.74	0.90	800	1000	1100	800
2	2.375	3.75	0.154	2.067	3.65	3.71	1.86	800	1000	1100	800
2½	2.875	5.90	0.203	2.469	5.79	5.88	3.27	800	1000	1100	800
3	3.500	7.70	0.216	3.068	7.58	7.67	4.09	800	1000	1100	800
3½	4.000	9.25	0.226	3.548	9.11	9.27	5.92	1200	1200	1300	950
4	4.500	11.00	0.237	4.026	10.79	11.01	7.59	1200	1200	1300	950
5	5.563	15.00	0.258	5.047	14.62	14.90	9.38	.....	1200	1300	950
6	6.625	19.45	0.280	6.065	18.97	19.33	12.92	.....	1200	1300	950
8	8.625	25.55	0.277	8.071	24.70	25.44	23.18	.....	1200	1300	950
* 8	**8.625**	**29.35**	**0.322**	7.981	**28.55**	29.25	23.18	.....	1300	1600	950
10	10.750	32.75	0.279	10.192	31.20	32.20	31.55	.....	1000	1200	800
10	10.750	35.75	0.307	10.136	34.24	35.20	31.55	.....	1000	1200	800
*10	**10.750**	**41.85**	**0.365**	10.020	**40.48**	41.35	31.55	.....	1200	1400	800
12	12.750	45.45	0.330	12.090	43.77	45.40	49.27	.....	1000	1200	800
*12	**12.750**	**51.15**	**0.375**	12.000	**49.56**	51.10	49.27	.....	1100	1200	800
14D	14.000	57.00	0.375	13.250	54.57	55.80	45.83	.....	950	1100	750
16D	16.000	65.30	0.375	15.250	62.58	64.08	55.83	.....	850	1000	700
18D	18.000	73.00	0.375	17.250	70.59	72.37	66.53	.....	750	900	600
20D	20.000	81.00	0.375	19.250	78.60	80.70	79.37	.....	700	800	550

[1]Nominal weights, threads and coupling (Col. 3), are shown for the purpose of identification in ordering. Calculated weights, threads and coupling (Col. 7), are based on 20-ft lengths. See Par. 38 for weights applying to longer or shorter lengths.

[2]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

[3]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe. Pressures shown for sizes 4-in. nominal and smaller apply also to butt-welded open-hearth-iron pipe, and in sizes 2-in. nominal and smaller apply to butt-welded wrought-iron pipe.

*Dimensions and weights shown in bold face are the same as for ASA B 36.10 standard-wall pipe in this diameter.

NOTE: Lap-welded pipe is produced currently in 2⅜-in. through 16-in. outside diameters.

STANDARD-WEIGHT PLAIN-END LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7	8	9
					Test Pressure, psi., min.			
					Steel			Iron
Size: Nominal, in.	Outside Diameter, in. D	Plain-End Weight, lb. per ft.	Wall Thickness[1], in. t	Inside Diameter[1], in. d	Butt-Welded	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[2]
⅛	0.405	0.24	0.068	0.269	700	700	700	700
¼	0.540	0.42	0.088	0.364	700	700	700	700
⅜	0.675	0.57	0.091	0.493	700	700	700	700
½	0.840	0.85	0.109	0.622	700	700	700	700
¾	1.050	1.13	0.113	0.824	700	700	700	700
1	1.315	1.68	0.133	1.049	700	7.00	700	700
1¼	1.660	2.27	0.140	1.380	1000	1200	1300	1000
1½	1.900	2.72	0.145	1.610	1000	1200	1300	1000
2	2.375	3.65	0.154	2.067	1000	1200	1300	1000
2½	2.875	5.79	0.203	2.469	1000	1200	1300	1000
3	3.500	7.58	0.216	3.068	1000	.....	.....	.....
3½	4.000	9.11	0.226	3.548	1200	.....	.....	.....
4	4.500	10.79	0.237	4.026	1200	.....	.....	.....

[1]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

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[2]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe. Test pressures apply also to butt-welded open-hearth-iron pipe. Test pressures for sizes 2-in. nominal and smaller apply also to butt-welded wrought-iron pipe.

NOTE: Lap-welded steel pipe conforming to Table 5 is produced currently only in the 2-in. and 2½-in. nominal sizes.

REGULAR-WEIGHT PLAIN-END LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7
				Test Pressure, psi., min.		
				Steel		Iron
Size: Outside Diameter, in. D	Plain-End Weight, lb. per ft.	Wall Thickness[1], in. t	Inside Diameter[1], in. d	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[2]
3½	6.63	0.188	3.124	1900	2200	1500
3½	7.58	0.216	3.068	2200	2500	1800
3½	8.68	0.250	3.000	2500	2500	2100
3½	9.67	0.281	2.938	2500	2500	2300
4½	8.64	0.188	4.124	1500	1800	1200
4½	10.00	0.219	4.062	1700	2000	1400
4½	10.79	0.237	4.026	1900	2200	1500
4½	11.35	0.250	4.000	2000	2300	1600
4½	12.67	0.281	3.938	2200	2500	1800
4½	13.98	0.312	3.876	2500	2500	2000
6⅝	12.89	0.188	6.249	1000	1200	800
6⅝	14.97	0.219	6.187	1200	1400	950
6⅝	17.02	0.250	6.125	1400	1600	1100
6⅝	18.97	0.280	6.065	1500	1800	1200
6⅝	21.07	0.312	6.001	1700	2000	1400
6⅝	23.06	0.344	5.937	1900	2200	1500
6⅝	25.03	0.375	5.875	2000	2400	1600
8⅝	16.90	0.188	8.249	800	900	650
8⅝	19.64	0.219	8.187	900	1100	750
8⅝	22.36	0.250	8.125	1000	1200	850
8⅝	24.70	0.277	8.071	1200	1300	950
8⅝	27.74	0.312	8.001	1300	1500	1000
8⅝	28.55	0.322	7.981	1300	1600	1000
8⅝	30.40	0.344	7.937	1400	1700	1100
8⅝	33.04	0.375	7.875	1600	1800	1300
8⅝	38.26	0.438	7.749	1800	2100	1500
10¾	24.60	0.219	10.312	750	850	600
10¾	28.04	0.250	10.250	850	1000	700
10¾	31.20	0.279	10.192	1000	1200	800
10¾	34.24	0.307	10.136	1000	1200	800
10¾	38.20	0.344	10.062	1100	1300	900
10¾	40.48	0.365	10.020	1200	1400	1000
10¾	48.19	0.438	9.874	1500	1700	1200
12¾	33.38	0.250	12.250	700	800	600
12¾	37.45	0.281	12.188	800	850	650
12¾	41.51	0.312	12.126	900	1000	700
12¾	43.77	0.330	12.090	1000	1200	800
12¾	45.55	0.344	12.062	1000	1200	800
12¾	49.56	0.375	12.000	1100	1200	850
12¾	57.53	0.438	11.874	1200	1400	1000
14	45.68	0.312	13.376	800	950	650
14	50.14	0.344	13.312	900	1000	700
14	54.57	0.375	13.250	950	1100	750
14	63.37	0.438	13.124	1100	1300	900
14	72.09	0.500	13.000	1300	1500	1000
16	52.36	0.312	15.376	700	800	550
16	57.48	0.344	15.312	750	900	600
16	62.58	0.375	15.250	850	1000	700
16	72.72	0.438	15.124	1000	1100	800
16	82.77	0.500	15.000	1100	1300	900
18	59.03	0.312	17.376	600	750	500
18	64.82	0.344	17.312	700	800	550
18	70.59	0.375	17.250	750	900	600
18	82.06	0.438	17.124	900	1000	700
18	93.45	0.500	17.000	1000	1200	800
20	65.71	0.312	19.376	550	650	450
20	72.16	0.344	19.312	600	700	500
20	78.60	0.375	19.250	700	800	550
20	91.41	0.438	19.124	800	900	650
20	104.13	0.500	19.000	900	1000	700

[1]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

[2]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe.

NOTE: Lap-welded pipe is not produced currently in outside diameters larger than 16 in.

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TOLERANCES ON DIMENSIONS AND WEIGHTS

	Tolerance
Outside diameter, *D*:	
1.900 in. and smaller	+ 0.016 in. — 0.031 in.
2⅜ in. and larger	± 1 per cent

Plain-end pipe 10¾ in. and smaller, shall not be more than 1/64 in. smaller than the tabulated outside diameter for a distance of 4 in. from the end of the pipe and shall permit the passage over the ends, for a distance of 4 in., of a ring gage which has a bore 1/16 in. larger than the tabulated outside diameter of the pipe. Plain-end pipe 12¾ in. to 20 in., inclusive, shall not be more than 1/32 in. smaller than the tabulated outside diameter for a distance 4 in. from the end of the pipe and shall permit passage over the ends, for a distance of 4 in., of a ring gage which has a bore 3/32 in. larger than the tabulated outside diameter of the pipe. At the option of the manufacturer, the minimum outside diameter of pipe in sizes 20 in. and smaller may be measured with a diameter tape. Plain-end pipe 22 in. and larger shall not be more than 1/32 in. smaller nor more than 3/32 in. larger than the tabulated outside diameter for a distance of 4 in. from the end of the pipe, as measured with a diameter tape.

Wall thickness, *t*:	
For seamless pipe in all sizes and welded pipe in sizes 18 in. and smaller	— 12.5 per cent
For welded pipe in sizes 20 in. and larger	— 10.0 per cent

Weight:

Single lengths:

Standard-weight, regular-weight, extra-strong, and double-extra-strong pipe (Tables 4, 5, 6, 8, and 9)	+ 10.0 per cent — 3.5 per cent
Special plain-end pipe (Table 7)	+ 10.0 per cent — 5.0 per cent
Carload lots:	
All series	— 1.75 per cent

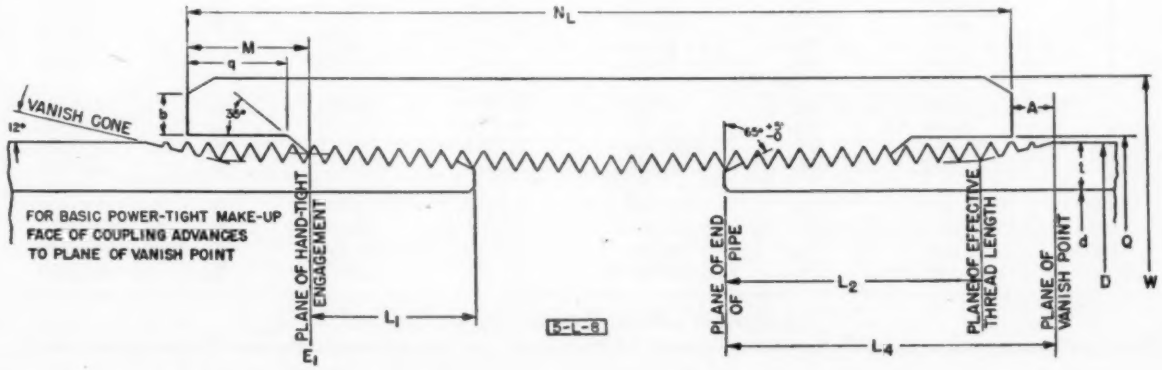
Weight tolerances apply to the calculated weights for threaded-and-coupled pipe and to the tabulated weights for plain-end pipe.

STANDARD LENGTHS

	Minimum Permissible Length	Minimum Average Length
Threaded pipe:		
Entire shipment	16 ft. 0 in.	
95 per cent or more of lengths in entire shipment	18 ft. 0 in.	
Plain-end pipe:		
Entire shipment	9 ft. 0 in. (Unless otherwise agreed upon)	17 ft. 6 in.

When the average length of plain-end pipe agreed upon between the purchaser and the manufacturer, is in excess of 20 ft, not over 10 per cent of the lengths furnished on the entire shipment shall be shorter than 75 per cent of the average length agreed upon, and no piece shall be shorter than 40 per cent of the average length agreed upon; the average length, however, shall be maintained. Upon agreement between the purchaser and the manufacturer, these stipulations shall apply to each carload.

LINE PIPE HAND-TIGHT MAKE-UP



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LINE PIPE THREAD DIMENSIONS

1	2	3	4	5	6	7	8	9
Size: Nominal	No. of Threads per Inch	Length: End of Pipe to Hand-Tight Plane L_1	Length: Effective Threads L_3	Total Length: End of Pipe to Vanish Point L_4	Pitch Diameter at Hand-Tight Plane E_1	End of Pipe to Center of Coupling, Power-Tight Make-Up J	Length: Face of Coupling to Hand-Tight Plane M	Hand-Tight Standoff, thread turns A
⅛	27	0.180	0.2639	0.3924	0.37476	0.1389	0.1014	3
¼	18	0.200	0.4018	0.5946	0.48989	0.2179	0.2278	3
⅜	18	0.240	0.4078	0.6006	0.62701	0.2119	0.1938	3
½	14	0.320	0.5337	0.7815	0.77843	0.2810	0.2473	3
¾	14	0.339	0.5457	0.7935	0.98887	0.2690	0.2403	3
1	11½	0.400	0.6828	0.9845	1.23863	0.3280	0.3235	3
1¼	11½	0.420	0.7068	1.0085	1.58338	0.3665	0.3275	3
1½	11½	0.420	0.7235	1.0252	1.82234	0.3498	0.3442	3
2	11½	0.436	0.7565	1.0582	2.29627	0.3793	0.3611	3
2½	8	0.682	1.1375	1.5712	2.76216	0.4913	0.6392	2
3	8	0.766	1.2000	1.6337	3.38850	0.4913	0.6177	2
3½	8	0.821	1.2500	1.6837	3.88881	0.5038	0.6127	2
4	8	0.844	1.3000	1.7337	4.38713	0.5163	0.6397	2
5	8	0.937	1.4063	1.8400	5.44929	0.4725	0.6530	2
6	8	0.958	1.5125	1.9462	6.50597	0.4913	0.7382	2
8	8	1.063	1.7125	2.1462	8.50003	0.4788	0.8332	2
10	8	1.210	1.9250	2.3587	10.62094	0.5163	0.8987	2
12	8	1.360	2.1250	2.5587	12.61781	0.5038	0.9487	2
14 D	8	1.562	2.2500	2.6837	13.87263	0.5038	0.8717	2
16 D	8	1.812	2.4500	2.8837	15.87575	0.4913	0.8217	2
18 D	8	2.000	2.6500	3.0837	17.87500	0.4788	0.8337	2
20 D	8	2.125	2.8500	3.2837	19.87031	0.5288	0.9087	2

Included taper, all sizes, 0.0625 in. per in.

COUPLING DIMENSIONS AND TOLERANCES

1	2	3	4	5	6	7	8
Size: Nominal	Outside Diameter of Coupling W	Length N_L	Diameter of Recess Q	Depth of Recess q	Length: Face of Coupling to Hand-Tight Plane M	Width of Bearing Face b	Pitch Diameter at Hand-Tight Plane E_1
⅛	0.563	1 1/16	0.468	0.0347	0.1014	3/32	0.37476
¼	0.719	1⅝	0.603	0.1471	0.2278	3/32	0.48989
⅜	0.875	1⅝	0.738	0.1147	0.1938	3/32	0.62701
½	1.063	2⅛	0.903	0.1582	0.2473	1/16	0.77843
¾	1.313	2⅛	1.113	0.1516	0.2403	1/16	0.98887
1	1.576	2⅝	1.378	0.2241	0.3235	3/32	1.23863
1¼	2.054	2¾	1.723	0.2279	0.3275	3/32	1.58338
1½	2.200	2¾	1.963	0.2439	0.3442	3/32	1.82234
2	2.875	2⅞	2.469	0.2379	0.3611	⅛	2.29627
2½	3.375	4⅛	2.969	0.4915	0.6392	3/16	2.76216
3	4.000	4¼	3.594	0.4710	0.6177	3/16	3.38850
3½	4.625	4⅜	4.094	0.4662	0.6127	3/16	3.88881
4	5.200	4½	4.594	0.4920	0.6397	¼	4.38713
5	6.296	4⅝	5.657	0.5047	0.6530	¼	5.44929
6	7.390	4⅞	6.719	0.5861	0.7382	¼	6.50597
8	9.625	5¼	8.719	0.6768	0.8332	¼	8.50003
10	11.750	5¾	10.844	0.7394	0.8987	5/16	10.62094
12	14.000	6⅛	12.844	0.7872	0.9487	5/16	12.61781
14 D	15.000	6⅜	14.094	0.7136	0.8717	5/16	13.87263
16 D	17.000	6¾	16.094	0.6658	0.8217	5/16	15.87575
18 D	19.000	7⅛	18.094	0.6773	0.8337	5/16	17.87500
20 D	21.000	7⅝	20.094	0.7490	0.9087	5/16	19.87031

Tolerance on outside diameter W, ± 1 per cent

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WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

Standard thicknesses and weights of cast iron mechanical joint pipe centrifugally cast in metal and sand lined molds for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 18,000 psi full length bursting tensile, 40,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Thickness ins.	Outside Diam. ins.	Weight Based On 12 ft. Lgth.* Avg. per ft.	12 ft. Lgth.* per Lgth.	16 ft. Lgth.* Avg. per ft.	16 ft. Lgth.* per Lgth.	16½ ft. Lgth.* Avg. per ft.	16½ ft. Lgth.* per Lgth.	18 ft. Lgth.* Avg. per ft.	18 ft. Lgth.* per Lgth.	20 ft. Lgth.* Avg. per ft.	20 ft. Lgth.* per Lgth.
Class 10—10 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.73	32.00			241.5	3865	241.0	3975			238.0	4760
36	.81	38.30			322.4	5160						
42	.90	44.50			416.5	6665						
48	.98	50.80			519.0	8305						
Class 50—50 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.79	32.00			259.5	4150	259.0	4275			256.0	5120
36	.87	38.30			343.9	5500						
42	.97	44.50			445.7	7130						
48	1.06	50.80			557.1	8915						
Class 100—100 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.54	17.40	97.1	1165	95.0	1520	94.9	1565	94.5	1700	94.0	1880
20	.62	21.60	138.7	1665	135.9	2175	135.7	2240	134.9	2430	134.2	2685
24	.68	25.80	182.2	2185	178.5	2855	178.1	2940	177.2	3190	176.2	3525
Class 150—150 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.

(1) Class 22 thickness.

(2) Class 23 thickness offers increased factor of safety and is recommended for use in areas of dense population and heavy traffic.

References: A.S.A.—A-21.7—pipe cast in metal molds. A.S.A.—A-21.9—pipe cast in sand lined molds. A.S.A.—A-21.11—mechanical joints.

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WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

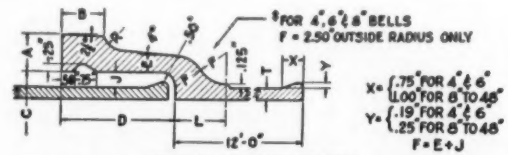
Standard thicknesses and weights of cast iron mechanical joint pit cast pipe for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 11,000 psi full length bursting tensile, 31,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Outside Diam. ins.	Class 10 10 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 50 50 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 100 100 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.	Class 150 150 lb. Pressure Thickness ins.	Weight Based on 12 ft. Lgth.* Avg. per ft.	per Lgth.
4	4.80	.40	18.6	225	.40	18.6	225	.40	18.6	225	.40	18.6	225
6	6.90	.43	29.2	350	.43	29.2	350	.43	29.2	350	.43	29.2	350
8	9.05	.46	41.3	495	.46	41.3	495	.46	41.3	495	.46	41.3	495
10	11.10	.50	55.4	665	.50	55.4	665	.50	55.4	665	.50	55.4	665
12	13.20	.54	71.2	855	.54	71.2	855	.54	71.2	855	.54	71.2	855
16	17.40	.58	103.7	1245	.58	103.7	1245	.58	103.7	1245			
20	21.60	.66	147.2	1765	.66	147.2	1765	.71	157.1	1885			
24	25.80	.74	197.2	2365	.74	197.2	2365	.80	211.4	2535			
30	32.00	.87	291.8	3500	.87	291.8	3500						
36	38.30	.97	392.0	4705	.97	392.0	4705						
42	44.50	1.07	503.0	6035	1.07	503.0	6035						
48	50.80	1.18	634.3	7610	1.18	634.3	7610						

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.

References: Thicknesses—A.S.A.—A-21.3—pit cast for gas Mechanical joint—A.S.A.—A-21.11.



BELL NO. 1—STANDARD BELL

Nom. Diam. Ins.	Actual Outside Diam. Ins.	T	Actual Inside Diam. Ins.	Dimensions in Inches A	B	C	D	E	F	J	L	R	Approximate Weight in Pounds Bell †	Per ft. *	12' 0" Lgth.
4	4.80	.40	4.00	1.30	1.50	5.80	4.00	.59	21.09	.50	3.25	.75	27.0	19.50	234
6	6.90	.43	6.04	1.40	1.50	7.90	4.00	.62	21.12	.50	3.25	.80	39.5	30.58	367
8	9.05	.45	8.15	1.50	1.50	10.05	4.00	.69	21.19	.50	3.25	.80	52.8	42.42	509
10	11.10	.49	10.12	1.50	1.50	12.10	4.00	.69	1.19	.50	2.10	.90	57.93	55.91	671
12	13.20	.54	12.12	1.60	1.50	14.20	4.50	.75	1.25	.50	2.30	1.00	79.47	73.83	886
16	17.40	.62	16.16	1.80	1.75	18.40	4.50	.90	1.40	.50	2.50	1.10	125.18	112.58	1351
20	21.60	.68	20.24	2.00	1.75	22.85	4.50	.97	1.60	.63	2.80	1.15	169.10	153.83	1846
24	25.80	.76	24.28	2.10	2.00	27.05	5.00	1.05	1.68	.63	2.80	1.25	235.10	206.41	2477
30	31.74	.85	30.04	2.30	2.00	32.99	5.00	1.15	1.78	.63	3.00	1.30	315.20	284.00	3408
36	37.96	.95	36.06	2.50	2.00	39.21	5.00	1.25	1.88	.63	3.20	1.40	410.20	379.25	4551
42	44.20	1.07	42.06	2.80	2.00	45.45	5.00	1.40	2.03	.63	3.40	1.45	537.50	497.66	5972
48	50.50	1.26	47.98	3.00	2.00	51.75	5.00	1.50	2.13	.63	3.60	1.60	657.00	663.50	7962

Note—Pipe heavier than these standards may be made by reducing the cores, or internal diameters "C" and "D"; same for specials.

Dimension "L" for sizes 4", 6" and 8", and Dimension "F", shown in sketch as 2.50 (outside radius only), apply to bells of *straight pipe only*. For bells of *special castings* the correct dimensions for "F" and "L" are.

Size	"F"	"L"
4	1.09	1.90
6	1.12	2.00
8	1.19	2.10

*Weight per foot includes Bell and Bead.

†Weight of Bell includes only metal beyond O. D. of pipe.

‡See Sketch for Special outside radius dimensions for 4", 6" and 8" Bells.

The simplicity, speed and high quality of arc welding has resulted in almost all cross-country pipe lines being completely welded.

Following is a general description of modern practice in the construction of oil and gas lines, using the plain end joint with liner for gas lines, and the plain end joint without liner for oil lines.

Where so called "roll welding" of pipe sections can be done, out in front of the entire construction gang goes the lineup and tacking crew. Aided by a tractor and hoist, they put the pipe lengths on ball-bearing dollies for rolling. The tack welder tacks the adjacent lengths of pipe together usually at four points in the circumference. He joins as many lengths as the nature of the line and the contour of the country will permit. The long tack-welded section is then left on the dollies ready for the firing line welders who follow close behind.

In recent years the "stove-pipe" method has come into widest use, especially for lines over rough terrain where roll-welding of long sections is difficult. It is also used over fairly smooth or rolling country. Here, all joints (usually plain end without liner) are position-welded like bell-hole joints. One joint at a time is added to the line, making it possible to reduce the size of the crew and amount of equipment, and keep operations bunched together under one supervisor. During alignment and tacking, the joint is usually held in place by a line-up clamp or "grasshopper." After tacking, two bell-hole welders work simultaneously on both side of the joint, making the complete first bead, each welder coming down from the top.

The wall thickness of the pipe for river crossings is generally 50 per cent to 100 per cent greater than that used in the rest of the line. The pipe is roll-welded and bell-hole welded into a section long enough to cross the river. Each joint is often reinforced by a welded-on sleeve. Special river clamps, four to ten feet long and weighing 1000 to 3000 lbs each are often bolted to the pipe at intervals, serving as a means of anchoring. The pipe section is then attached by cable to tractors and pulled onto pontoons from which it is guided by stakes into a dredged out ditch in the river bottom. It is usually buried at a minimum depth of eight feet.

The welding speed data in the accompanying tables are based on the average time consumed in making all welds on an average length pipe line from start to finish of the job, including delays, outages and moving time. In other words, it is the average production that can be expected per joint per hour on pipe line construction except where otherwise noted.

RECOMMENDED SIZES OF ELECTRODE FOR PIPE LINE WELDING

	Roll welding without back-up ring			Position welding without back-up ring "stove pipe" or "tie in" method		
Size	Stringer bead	Second bead	Third bead	Stringer bead	Second bead	Third bead
4″	5/32″	3/16″	1/4″			
6″	5/32″	1/4″	1/4″	5/32″	5/32″	3/16″
8″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
10″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
12″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
14″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
16″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
18″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
20″	5/32″ or 3/16″	1/4″	1/4″ or 3/16″	5/32″	5/32″	3/16″
22″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
24″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
26″	5/32″ or 3/16″	1/4″	1/4″ or 5/16″	5/32″	5/32″	3/16″
30″	5/32″ or 3/16″	1/4″	1/4″ or 3/16″	5/32″	5/32″	3/16″

Position welding with back-up ring: Use 3/16 in. rod for all beads on all sizes of pipe.

Note: Use 3/16 in. electrode on additional beads when necessary.

AVERAGE SPEEDS FOR PIPE LINE WELDING

	Roll welding without back-up ring	Position welding without back-up ring
Size	Average welds per hour	(After 1st bead run by tackers) Average welds per hour
6	6.0	6.5
8	5.5	5.0
10	4.0	4.5
12	3.5	3.75
14	3.0	3.0
16	2.75	2.50
18	2.50	2.25
20	2.25	2.25
22	2.1	2.0
24	2.0	2.0
26	1.5	1.25
30	1.25	1.0

Note: Roll and Position Welding Without Back-up Ring: For all sizes of pipe use a space of 1/16 in. to 1/8 in.

POUNDS OF ELECTRODE PER WELD*

Size pipe	pounds
6″	.75
8″	1.00
10″	1.25
12″	1.50
14″	1.75
16″	2.00
18″	2.25
20″	2.50
22″	2.75
24″	3.00
26″	3.25
30″	4.00

*Based on 1/4 in. to 5/16 in. wall thickness pipe.

The firing line crew, including several welders, completes the welds of the long sections. These operators weld at the top of the pipe while a helper turns the pipe by means of a chain pipe wrench. Thus, all welding is done in a flat, down-hand position, and by using large-size electrodes (¼″, 5/16″ and sometimes ⅜″) and heavy welding current, high welding speeds are obtained. After completion of each bead, a helper cleans all of the slag from the weld. Each completed weld is inspected for any imperfections before the welder proceeds to the next joint. When the section is entirely welded the pipe is rolled off the dollies and the pipe sections are painted and then joined into a continuous stretch by "bell-hole" welding.

This pipe is placed on timber skids near or over the trench and, in this position, it is "bell-hole" welded. Here, instead of having the pipe rolled beneath the arc, the operator plies the arc around the pipe. For these welds, he uses smaller sized electrodes (5/32″ or 3/16″) with 125 to 200 amperes.

DIMENSION DATA ON TELESCOPIC WET SEAL GAS HOLDERS

Capacity Thousand Cubic Feet	Number of Lifts	Tank Dimensions Diam.	Tank Dimensions Height	Number of Columns	Pressure Inflated with Air — LIFTS 1st	2nd	3rd	4th	All	Usual Conn. Diam.	FOUNDATION Diameter	Excavation Cu.Yds.	Concrete Cu.Yds.	Water Load per Sq. Ft. on Bottom	Water To Fill Tank Gallons
5	One	25'-0"	12'-6"	4	4.8"				4.8"	6"	27'-6"	69	54	767	45,000
10	One	32'-0"	15'-6"	4	5.1"				5.1"	6"	34'-6"	84	69	955	91,700
15	One	37'-0"	17'-0"	4	4.5"				4.5"	10"	39'-6"	96	81	1048	134,700
20	One	40'-6"	18'-6"	5	4.6"				4.6"	10"	43'-0"	105	90	1142	175,900
25	One	42'-0"	21'-3"	5	4.8"				4.8"	10"	44'-6"	109	94	1315	207,400
30	One	44'-6"	22'-6"	6	4.8"				4.8"	12"	47'-0"	134	108	1395	258,800
40	One	50'-6"	23'-0"	6	5.1"				5.1"	12"	53'-0"	164	138	1422	340,700
50	One	55'-6"	23'-8"	6	4.8"				4.8"	12"	58'-0"	168	142	1465	424,300
60	One	59'-6"	24'-6"	6	4.6"				4.6"	12"	62'-0"	189	155	1533	505,000
75	One	64'-0"	26'-3"	8	4.6"				4.6"	12"	66'-6"	198	172	1628	625,700
100	One	71'-3"	28'-0"	8	4.4"				4.4"	12"	73'-9"	226	200	1735	828,200
125	One	79'-3"	28'-0"	9	4.5"				4.5"	12"	81'-9"	259	233	1735	840,700
75	Two	50'-6"	23'-0"	9	5.6"				9.7"	12"	53'-0"	165	139	1422	340,700
100	Two	57'-5"	23'-10"	9	5.4"				9.1"	12"	59'-11"	190	164	1478	457,000
125	Two	62'-0"	25'-6"	9	5.9"				10.0"	12"	64'-6"	206	180	1582	570,200
150	Two	66'-6"	26'-0"	9	5.6"				9.4"	16"	69'-0"	248	208	1610	669,000
200	Two	73'-2"	28'-3"	9	5.2"				8.8"	16"	75'-8"	278	238	1752	882,000
250	Two	79'-8"	29'-9"	10	5.5"				9.1"	16"	82'-2"	308	268	1848	1,101,100
300	Two	84'-3"	31'-4"	10	5.5"				9.1"	16"	86'-9"	332	292	1945	1,294,900
400	Two	93'-3"	34'-0"	10	6.1"				9.9"	24"	95'-9"	403	348	2110	1,729,300
500	Two	102'-0"	35'-2"	12	5.4"				8.9"	24"	104'-6"	455	400	2185	2,134,300
300	Three	75'-0"	28'-3"	9	5.0"	8.3"			11.2"	16"	78'-0"	316	276	1752	925,300
400	Three	80'-0"	32'-4"	10	5.5"	9.1"			12.3"	24"	83'-0"	364	309	2010	1,206,100
500	Three	93'-9"	28'-10"	10	5.2"	8.2"			10.8"	24"	96'-9"	440	385	1788	1,475,600
600	Three	95'-4½"	34'-0"	10	6.1"	9.8"			13.0"	24"	98'-4½"	450	395	2110	1,805,000
750	Three	104'-7"	35'-0"	12	6.0"	9.6"			12.6"	24"	107'-7"	504	449	2170	2,240,600
1,000	Three	118'-6"	35'-9"	14	5.9"	9.5"			12.7"	24"	121'-6"	605	550	2220	2,928,700
1,500	Three	142'-5"	36'-3"	16	5.5"	8.7"			11.4"	30"	145'-5"	857	754	2250	4,293,700
1,000	Four	105'-0"	35'-0"	12	7.2"	11.1"	14.7"		17.9"	30"	108'-0"	605	502	2185	2,245,000
1,500	Four	136'-6"	30'-10"	14	5.5"	8.5"	11.2"		13.6"	30"	139'-6"	843	740	1915	3,350,000
2,000	Four	145'-5"	35'-8"	16	5.9"	8.6"	11.1"		13.0"	36"	148'-5"	976	863	2215	4,411,300
3,000	Four	175'-0"	36'-3"	18	5.5"	8.4"	11.0"		13.3"	36"	178'-0"	1253	1140	2250	6,477,000
5,000	Five	204'-4"	35'-9"	22	5.2"	7.5"	9.6"	11.7"	13.5"	36"	207'-4"	1613	1500	2220	8,709,700
6,000	Five	210'-2"	40'-6"	22	5.8"	8.1"	10.4"	12.5"	14.3"	42"	213'-2"	1739	1590	2520	10,477,300
8,000	Five	240'-9"	40'-4"	24	6.0"	8.3"	10.5"	12.7"	14.5"	42"	243'-9"	2129	1980	2500	13,670,800
10,000	Five	276'-6"	38'-2"	28	5.1"	7.0"	8.7"	10.4"	14.7"	42"	279'-6"	2639	2490	2375	17,031,300

STORAGE AND HANDLING OF LIQUEFIED PETROLEUM GASES

General. The term "liquefied petroleum gases" as used in these standards shall mean and include any material which is composed predominantly of any of the following hydrocarbons, or mixtures of them; propane, propylene, butanes (normal butane or isobutane), and butylenes.

Under moderate pressure the gases liquefy, but upon relief of the pressure are readily converted into the gaseous phase. At atmospheric pressure and below 31 F. butane is a liquid. Propane is a liquid at atmospheric pressure at temperatures below minus 44 F. and normally does not present a flammable liquid hazard.

Rapid vaporization takes place at temperatures above the boiling points (butane about 30 F.; propane about minus 44 F.). Normal storage of these gases is as a liquid under pressure.

The following standards, here given in part, are intended to apply to the design, construction, location, installation, and operation of liquefied petroleum gas systems. These standards do not apply to marine terminals, pipe line and similar large volume terminals, natural gasoline plants, refineries, tank farms, or to chemical and utility gas manufacturing plants where specific approval of construction and installation plans is obtained from regulatory bodies having jurisdiction, provided such approval is based on substantially equivalent requirements.

Odorizing Gases. All liquefied petroleum gases shall be effectively odorized by an approved agent of such character as to indicate positively, by a distinctive odor, the presence of gas down to concentration in air of not over one-fifth the lower limit of combustibility.

Note: The low limits of combustibility of the more commonly used liquefied petroleum gases are: Propane, 2.15 per cent; Butane, 1.55 per cent. These figures represent volumetric percentages of gas-air mixtures in each case.

Location of Containers and Regulating Equipment. Containers and first stage regulating equipment shall be located outside of buildings other than those especially provided for this purpose. Except as herein provided, each individual container shall be located with respect to nearest important building or group of buildings or line of adjoining property which may be built upon in accordance with the following table.

Water capacity per container	Minimum distance		Dist. bet. aboveground containers
	Underground	Aboveground	
Less than 125 gallons	10 feet	None	None
125 to 500 gallons	10 feet	10 feet	3 feet
501 to 1,200 gallons	25 feet	25 feet	3 feet
Over 1,200 gallons	50 feet	50 feet	5 feet

In cases of bulk storage in heavily populated or congested areas, the inspection department having jurisdiction shall determine restrictions of individual container capacity, total storage, and distance to line of adjoining property which may be built on and other reasonable protective methods.

In industrial installations involving containers of 150,000 gallons aggregate capacity or more, where serious mutual exposures between the container and adjacent properties prevail, the enforcing authority having jurisdiction may require fire walls designed and constructed in accordance with good engineering practice.

In the case of buildings devoted exclusively to gas manufacturing and distributing operations the above distances may be reduced provided that in no case shall containers of capacity exceeding 500 gallons be located closer than 10 ft to such gas manufacturing and distributing buildings.

Readily ignitable material such as weeds and long dry grass shall be removed within ten feet of any container.

Container Valves and Accessories, Filler Pipes and Discharge Pipes. All shut-off valves and accessory equipment (liquid or gas) shall be approved for use with liquefied petroleum gas, and designed for not less than the maximum pressure to which they may be subjected. Valves which may be subjected to container pressure shall have a rated working pressure of at least 250 pounds per square inch gauge.

All connections to containers, except safety relief connections and gauging devices shall have shut-off valves located as close to the container as practicable.

The filling pipe inlet terminal shall not be located inside a building. Such terminals shall be located not less than 10 feet from any building and preferably not less than 5 feet from any driveway, and shall be located in a protective housing built for the purpose.

The filling connection shall be fitted with an approved combination back-pressure check valve and excess flow valve; a double or 2 back-pressure check valves; or a positive shut-off valve, in conjunction with either an internal back-pressure valve or an internal excess flow valve.

All liquid and vapor connections to containers except filling pipes and safety relief connections shall be equipped with approved automatic excess flow valves, except that no excess flow valve is required in the withdrawal service line, provided that:

1. The discharge from the service outlet is controlled by a suitable manually operated shut-off valve:
   (a) threaded directly into the service outlet of the container,
   (b) or which is an integral part of a substantial fitting threaded into or on the service outlet of the container,
   (c) or threaded directly into a substantial fitting threaded into or on the service outlet of the container.
2. The shut-off valve is equipped with an attached handwheel or the equivalent.
3. The controlling orifice between the contents of the container and the outlet of the shut-off valves does not exceed 5/16 in. in diameter for vapor withdrawal systems and ⅛ in. in diameter for liquid withdrawal systems.
4. An approved pressure-reducing regulator is directly attached to the outlet of the shut-off valve and is rigidly supported, or that an approved pressure-reducing regulator is attached to the outlet of the shut-off valve by means of a suitable flexible connection not longer than 20 in. and is rigidly supported.
5. Such systems' total water capacity does not exceed 1,200 U. S. gallons.

All inlet and outlet connections except safety relief valves, liquid level gauging devices and pressure gauges on containers of 1,200 gallons water capacity, or more, and on any container used to supply fuel directly to an internal combustion engine, shall be labeled to designate whether they communicate with vapor or liquid space. Labels may be on valves.

Excess flow valves where required by these standards shall close automatically at those rated flows of vapor or liquid as specified by the manufacturer. The connections or line including valves, fittings, etc., being protected by an excess flow valve shall have a greater capacity than the rated flow of the excess flow valve.

Liquid level gauging devices which are so constructed that outward flow of container contents shall not exceed that passed by a No. 54 drill size opening, need not be equipped with excess flow valves.

Openings from tank or through fittings attached directly on tank to which pressure gauge connection is made need not be equipped with excess flow valve if such openings are protected by not larger than No. 54 drill size opening.

Excess flow and back pressure check valves where required by these standards shall be located inside of the container or at a point outside where the line enters the container; in the latter case, installation shall be made in such manner than any undue strain beyond the excess flow or back pressure check valve will not cause breakage between the container and such valve.

Excess flow valves may be designed with a by-pass, not to exceed a 60 drill size opening to allow equalization of pressures.

Piping, Tubing, and Fittings. Piping or tubing* shall be wrought iron, steel, brass or copper pipe, or except as hereinafter provided, seamless copper, brass, steel or other approved gas tubing. All piping or tubing shall be suitable for a working pressure of not less than 125 pounds per square inch. Copper tubing may be of the standard grade K or L. Aluminum tubing shall not be used in exterior locations or where it passes through masonry or plaster walls or insulation.

Pipe joints may be screwed, flanged, welded, brazed or soldered with a solder having a melting point of over 1000 F. Where fittings are used they shall have a working pressure of at least 125 pounds in systems where the operating pressure is 125 pounds per square inch or less. Extra heavy fittings shall be used for pressure exceeding 125 pounds per square inch or less. Cast iron fittings shall be prohibited. Joints on seamless copper, brass, steel, or non-ferrous gas tubing shall be made of approved gas tubing fittings or soldered with solders having a melting point exceeding 1000 F. Valve seat material, packing, gaskets, etc., shall be of such quality as to be resistant to the action of liquefied petroleum gas in the liquid phase.

Hose Specifications. Hose shall be fabricated of materials that are resistant to the action of liquefied petroleum gases.

Hose subject to container pressure shall be designed for a bursting pressure of not less than five times the pressure for which the container was designed. Hose connections when made shall be capable of withstanding a test pressure of twice the pressure for which the container is designed.

Filling densities. The "filling density" is defined as the per cent ratio of the weight of the gas in a container to the weight of water the container will hold at 60 F. The filling densities for storage containers shall not exceed the ratios following:

Maximum Permitted Filling Density

Specific gravity at 60°	Aboveground containers: 0 to 1200 gals.* total water cap.	Aboveground containers: Over 1200 gals. total water cap.	Underground containers all capacities
.473—.480	38%	41%	42%
.481—.488	39	42	43
.489—.495	40	43	44
.496—.503	41	44	45
.504—.510	42	45	46
.511—.519	43	46	47
.520—.527	44	47	48
.528—.536	45	48	49
.537—.544	46	49	50
.545—.552	47	50	51
.553—.560	48	51	52
.561—.568	49	52	53
.569—.576	50	53	54
.577—.584	51	54	55
.585—.592	52	55	56
.593—.600	53	56	57
.601—.608	54	57	58
.609—.617	55	58	59
.618—.626	56	59	60
.627—.634	57	60	61

*Interstate Commerce Commission filling densities effective on the date of adoption of this standard.

Safety Devices. Every container and every vaporizer, whether heated by artificial means or not, shall be provided with one or more safety relief valves of spring-loaded or equivalent type. These valves shall be arranged to afford free vent to the outer air with discharge of not less than 5 ft horizontally away from any opening into the building which is below such discharge. The area of the discharge shall be sufficient to prevent the building up of pressures in excess of 120 per cent of the maximum permitted setting of the safety relief valves on the container and in accordance with the regulations of the National Board of Fire Underwriters, as contained in its Pamphlet No. 58. (Revised January, 1947.)

Container safety relief valves shall be set to start to discharge as follows, with relation to the container type:

Containers	Minimum	Maximum
A.S.M.E.-U-68, U-69	100%	125%
A.S.M.E.-U-200, U-201	90	100
A.P.I.-A.S.M.E.	80	100

Electrical Connections and Open Flames. In vaporizer or pump houses, in cylinder filling rooms and similar locations, all electrical installations shall be in strict accordance with the requirements of the National Electrical Code for Class I, Group D hazardous locations.

In vaporizer or pump houses, in cylinder filling rooms and similar locations, open flames or other sources of ignition shall not be permitted.

Design Working Pressure and Classification of Storage Containers. Storage containers shall be designed and classified as follows:

"Container type"	For gases with vapor pressure not to exceed lbs. per sq. in. gauge at 100° F	Minimum design working pressure of containers by: A.S.M.E. code U-68 U-69	A.S.M.E. code U-200 U-201	A.P.I.-A.S.M.E. code
100	100	100 lb Ga.	113 lb Ga.	125 lb Ga.
125	125	125 lb Ga.	141 lb Ga.	156 lb Ga.
150	150	150 lb Ga.	169 lb Ga.	187 lb Ga.
175	175	175 lb Ga.	197 lb Ga.	219 lb Ga.
200	200	200 lb Ga.	225 lb Ga.	250 lb Ga.

The shell or head thickness of any container shall not be less than 3/16 inch.

NOTE: Because of low soil temperature usually encountered, and the insulating effect of the earth, the average vapor pressure of products stored in underground containers will be materially lower than when stored aboveground. This reduction in actual operating pressure therefore provides a substantial corrosion allowance for these containers when installed underground.

Capacity of Liquid Containers. No liquid storage container shall exceed 30,000 standard U. S. gallons capacity.

Installation of Storage Containers. Containers installed above ground (except "skid tanks") shall be provided with substantial masonry or non-combustible structural supports on firm masonry foundations.

Except as modified by the note, above ground containers shall be supported as follows:

Horizontal containers shall be mounted on saddles and secured thereto in such a manner as to permit expansion and contraction. Every container shall be so supported as to prevent the concentration of excessive loads on the supporting portion of the shell. Structural metal supports may be employed when they are protected against fire in an approved manner. Suitable means of preventing corrosion shall be provided on that portion of the container in contact with the foundations or saddles.

Note: Containers of 1,200 gallons water capacity or less may be installed with non-fireproof ferrous metal supports if mounted on concrete pads or footings, and if the distance from the outside bottom of the container shell to the ground does not exceed 24 in.

(Information and data from publications of the National Board of Fire Underwriters: Pamphlet No. 58 — Liquefied Petroleum Gases — March 1949. Pamphlet No. 59 — Liquefied Petroleum Gases at Utility Gas Plants—March 1949.)

TANK FORMULAS

The following formulas have been selected to facilitate the rapid calculation of capacities of various types of storage tanks in gallons and barrels.

Uniform Notations:

B — Capacity of each dished head in United States gallons.

B_2 — Total capacity of both dished heads in United States gallons.

C_B — Total capacity of tank in barrels (of 42 United States gallons).

C_G — Total capacity of tank in United States gallons.

C_{GF} — Capacity of cylindrical portion of tank in United States gallons per foot length. (Flat heads.)

D — Inside diameter of tank in feet.

G — Liquid contents of partially filled tank in United States gallons.

L — Length of cylindrical portion of tank in feet.

b — Dish of head, bead line to inside of plate (height of arc) in inches.

d — Inside diameter of tank in inches.

h — Depth or height of liquid in tank in inches.

l — Length of cylindrical portion of tank in inches.

r — Radius of dished head (where different from tank diameter) in inches.

Capacity of Vertical Cylindrical Tanks with Flat Heads

R — Inside radius of tank in feet.

H — Height of liquid in feet.

Capacity in United States gallons, per foot depth

$C_{gf} = 23.501\ R^2$.

Total capacity in United States gallons

$C_g = 23.501\ R^2H$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.56\ R^2H$.

Capacity of Horizontal Cylindrical Tanks with Flat Heads

Total capacity in United States gallons

$C_g = 0.0034\ d^2l$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.14\ D^2L$.

Capacity of Horizontal Cylindrical Tanks with Dished Heads

(where radius of dished head equals diameter of tank)

Total capacity in United States gallons

$C_g = 0.0034\ d^2l + 0.0004664\ d^3$.

Total capacity in United States gallons

$C_g = 5.875\ D^2L + 0.806\ D^3$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.14\ D^2L + 0.019\ D^3$.

Capacity of Dished Head of any Radius

Capacity of each dished head in United States gallons

$B = 0.0045333\ b^2\ (3r - b)$.

Capacity of Spherical Tanks

Total capacity in United States gallons

$C_g = 0.0022666\ d^3$.

Total capacity in United States gallons

$C_g = 3.9168\ D^3$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.093257\ D^3$.

Liquid Contents of partially filled Tanks

Horizontal Cylindrical Tanks with Flat Heads:

Liquid contents in United States gallons.

$$G = \frac{1}{231}\left[0.004363\ d^2\ \text{Cos}^{-1}\frac{d-2h}{d} - \frac{d-2h}{2}\sqrt{h(d-h)}\right].$$

The notation $\text{Cos}^{-1}\ \frac{d-2h}{d}$ (read inverse cosine of $\frac{d-2h}{d}$, or arc cosine $\frac{d-2h}{d}$) means the angle (in degrees) whose cosine is equal to $\frac{d-2h}{d}$.

The use of this inverse function can best be illustrated by an example:

Find the number of gallons contained in a horizontal cylindrical tank with flat heads, if the tank inside diameter is 100 inches, the length 50 inches, and the tank is filled with liquid to a depth of 10 inches. Substituting in the above formula,

$$G = \frac{50}{231}\left[0.004363(100)^2\text{Cos}^{-1}\ \frac{100-20}{100} - \frac{100-20}{2}\sqrt{10(100-10)}\right],$$

$$G = 0.21645\ [\ 43.63\ \text{Cos}^{-1}\ 0.80 - 40\sqrt{900}\ ].$$

But, as stated above, Cos^{-1} 0.80 means "the angle of which the cosine is 0.80." From a table of natural cosines the angle is found to be 36° 52′ or 36.87°. Substituting this value for Cos^{-1} 0.80 we have,

$G = 0.21645\ (43.63 \times 36.87 - 1200)$,

$G = 0.21645 \times 408.6$,

$G = 88.45$ gallons.

Note: In calculating liquid contents of partially filled tanks, use formula for tanks up to half full. For tanks over half full, calculate capacity of unfilled portion and subtract from capacity of full tank.

Spherical Tanks:

G = Liquid contents in United States gallons

$= 0.0022666h^2(3d - 2h)$.

VAPOR PRESSURES OF PROPANE, BUTANE AND ISOBUTANE

Temp. Deg. F.	Propane		Butane		Isobutane		Temp. Deg. F.
	Pressure—lbs. per sq. in.						
	Absolute	Gauge	Absolute	Gauge	Absolute	Gauge	
—75	6.37	*17.0					—75
—70	7.37	*14.9					—70
—65	8.48	*12.7					—65
—60	9.72	*10.1					—60
—55	11.1	* 7.3					—55
—50	12.6	* 4.3					—50
—45	14.4	* 0.6					—45
—40	16.2	1.5					—40
—35	18.1	3.4					—35
—30	20.3	5.6					—30
—25	22.7	8.0					—25
—20	25.4	10.7			7.50	*14.6	—20
—15	28.3	13.6			8.30	*13.0	—15
—10	31.4	16.7			9.28	*11.0	—10
— 5	34.7	20.0			10.4	* 8.8	— 5
0	38.2	23.5	7.3	*15.0	11.6	* 6.3	0
5	41.9	27.2	8.2	*13.2	13.1	* 3.3	5
10	46.0	31.3	9.2	*11.1	14.6	* 0.2	10
15	50.6	35.9	10.4	* 8.8	16.3	1.6	15
20	55.5	40.8	11.6	* 6.3	18.2	3.5	20
25	60.9	46.2	13.0	* 3.6	20.2	5.5	25
30	66.3	51.6	14.4	* 0.6	22.3	7.6	30
35	72.0	57.3	16.0	1.3	24.6	9.9	35
40	78.0	63.3	17.7	3.0	26.9	12.2	40
45	84.6	69.9	19.6	4.9	29.5	14.8	45
50	91.8	77.1	21.6	6.9	32.5	17.8	50
55	99.3	84.6	23.8	9.1	35.5	20.8	55
60	107.1	92.4	26.3	11.6	38.7	24.0	60
65	115.4	100.7	28.9	14.2	42.2	27.5	65
70	124.0	109.3	31.6	16.9	45.8	31.1	70
75	133.2	118.5	34.5	19.8	49.7	35.0	75
80	142.8	128.1	37.6	22.9	53.9	39.2	80
85	153.1	138.4	40.9	26.2	58.6	43.9	85
90	164.0	149.0	44.5	29.8	63.3	48.6	90
95	175.0	160.0	48.2	33.5	68.4	53.7	95
100	187.0	172.0	52.2	37.5	73.7	59.0	100
105	200.0	185.0	56.4	41.7	79.3	64.6	105
110	212.0	197.0	60.8	46.1	85.1	70.4	110
115	226.0	211.0	65.6	50.9	91.4	76.7	115
120	240.0	225.0	70.8	56.1	98.0	83.3	120
125	254.0	239.0	76.0	61.3	104.8	90.1	125
130	272.0	257.3	81.4	66.7	112.0	97.3	130
135	288.0	273.3	87.0	72.3	119.3	104.6	135
140	305.0	290.3	92.6	77.9	126.8	112.1	140
145			100.0	85.3	136.0	121.3	145
150			108.0	93.7	145.0	130.3	150
155			115.0	100.3	155.0	140.3	155
160			122.0	107.3	165.0	150.3	160
165			130.0	115.3	175.0	160.3	165
170			140.0	125.3	186.0	171.3	170
175			150.0	135.3	198.0	183.0	175
180			160.0	145.3	210.0	195.3	180

*Inches of mercury below one standard atmosphere (29.92 in.).

Dana, Jenkins, Burdick and Timm, Refrigerating Engineering, June 1926.

Design and Operation of Baltimore Oil Foggers

FEATURES that should be incorporated in the design of a hot oil fogger to obtain continuous trouble-free operation, adequate control of fogging rates and maximum fog stability are briefly as follows:

1. No heat should be applied directly to the oil. The necessary heat should be applied to the "sweep" gas before contracting the oil to be vaporized. In this way the possibility of the carbonization of the oil on heat transfer surfaces with consequent adverse effect on fogging rates is avoided.
2. The heated gas should preferably be made to flow counter-current to the oil in order to obtain maximum vaporization of the oil for a given sweep gas flow and temperature.
3. In order to adequately control the fogging rate, the fresh oil should be added to the heated gas stream in a positively controlled manner which eliminates any possibility of flooding and over-fogging.
4. In order to maintain constant fogging rates, the spent oil residue should be removed continuously from the vaporization tower of the fogging equipment and not permitted to return to or mix with the fresh fogging oil.
5. The hot gas carrying the oil vapor should be introduced directly into the main gas stream. In this way the gas is cooled rapidly and a high concentration of fog particles is avoided and coalescence thereby reduced.
6. Open flames should be eliminated to reduce fire and explosion hazards. This permits the installation of these foggers at the most advantageous locations.
7. As a further safety measure, the heating of large volumes of oil in the fogger should be avoided. The design should also permit the storage of fogging oil at any convenient, safe location.

The small fogger designed for an outlying station where oil requirements are limited to a few gallons per day is designed to operate at a station where the gas pressure is reduced. The sweep gas is passed through the fogger from the high to the low pressure main and the gas flow is controlled by adjusting the pressure regulator.

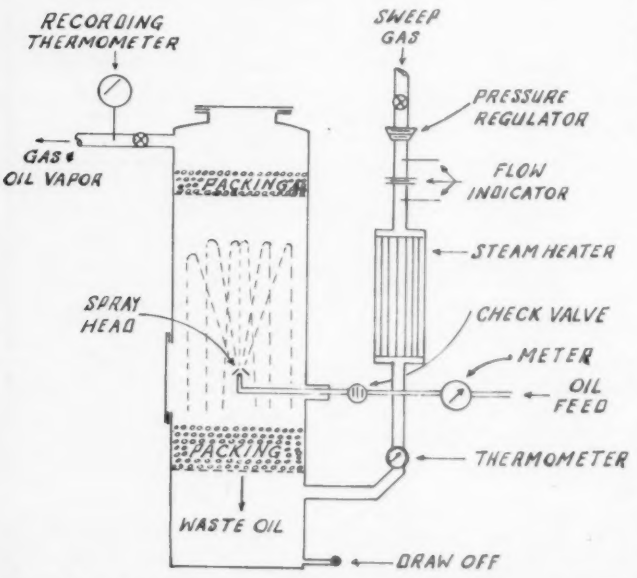


FIG. 1. High capacity-low pressure oil fogger 30,000 cu ft steam heated sweep gas per hr. Designed to fog 100 gal oil per day.

Two thermoregulators are connected in series and arranged so that if the controlling regulator should fail, the second will operate at a temperature 50 F higher.

The temperature of the gas is usually maintained at 350 to 400 F. However, it has been determined that temperatures as high as 500 F may be employed without decomposition of gas or oil. Use of higher temperatures permits increasing fogging rate.

The fogging rate is controlled by the rate at which oil is delivered to the tower.

Fresh oil is added continuously to the vaporizing tower and the uncaporized residue is collected in a reservoir at the bottom, out of contact with the gas stream. Not more than 80 to 90 per cent of the oil added should be vaporized in order that the residue may remain fluid and drain readily from the tower packing. The percentage of the oil vaporized may be controlled by either changing the sweep gas rate or the operating temperature.

Fig. 1 shows a large oil fogger designed for use at the principal distribution center where steam is readily available.

In this installation the sweep gas is heated by steam in a heat exchanger. The oil is atomized into free space between layers of Raschig rings.

Distance Tests

One fogger, when placed in operation, was fogging oil at a rate of 50 gallons per day, which was equivalent to ¾ of a gallon of oil per million cubic feet of gas. When oil had appeared at four test points in the distribution system and could be definitely identified as fogging oil, these distances from the fogger were noted:

Northeast test	2.4	miles
North test	8.8	miles
East test	3.9	miles
South test	6.1	miles

The excellent stability and transit of the fog produced by this equipment is also demonstrated by the fact that only neglilible amounts of oil have been found in the mains close to the fogging locations. Control is further demonstrated by the fact that excessive oil is found in customer services lines located close to the fogging points.

The fogging oil used is a paraffin base oil which has been acid washed and distilled. It is made from selected stock to assure stability. Its distillation range is

1	per cent over	587 F
5		596
20		601
50		610
70		623
90		646
99.3		668

The viscosity of the oil is approximately 50 seconds at 100 F, Saybolt Universal.

It is the practice to condition new or dry systems with oil fog at a rate of 1½ to 2 gallons of oil per million cubic feet of gas. It is believed that about one gallon per million is sufficient once the system becomes oil wet.

Because of the high stability and carry of the fog made with equipment these quantities are usually adequate. High fog concentration should be employed with caution because of possible trouble due to oil in customers' appliances.

American Gas Handbook, November 15, 1953.
Abstracted from article by O. W. Lusby.

Methods of Controlling Corrosion

Basically, corrosion in pipe line and distribution lines can be controlled by one or more general methods. These include the selection of right-of-way to avoid obvious or highly corrosive spots; coating of pipe with a protective film or wrapper; or imposing a flow of current on the pipe with galvanic cells or electronic rectifiers.

The right-of-way for a line is normally selected to approximate a straight line between points and at the same time permit ease of construction and maintenance. Where the corrosive areas indicated soil surveys are small, the pipe line right-of-way can in many cases be altered with out appreciably increasing construction or maintenance costs. Where highly corrosive areas are large, it is usually more economical to resort to a concentrated program of protective coatings and cathodic protection.

A number of pipe coatings for the control of external corrosion are in use at this time. Types include asphalts, coal tars, plastics, mastics, greases and concrete. Also, galvanizing is successfully used in some areas. Galvanized pipe is not generally considered well adapted for underground use because of galvanic corrosion. It is being used to good advantage in dry soils and for the prevention of atmospheric corrosion.

Concrete coatings were at one time very popular. However, the cost is relatively high and it presents some difficulty in handling. Since the coating has a tendency to absorb moisture, check and crack, its use is not extensive at this time.

Bituminous coatings, coal tar and asphalt, are probably the most widely used coating materials of the present day. Both are manufactured in a wide variety of specifications to meet the many application requirements. Coating thicknesses used are in the order of 3/32 of an inch. One of the most important steps in the application of the coating is the preparation of the pipe. The pipe should be clean, free of dirt, moisture, mill scale and the like, and should be primed with material to bond the coating to the pipe.

Plastics, which are inert to corrosive elements and are good electric insulating materials, are being used to a great extent on pipe line and distribution lines. Plastic in the form of hot coatings and wraps are in use. Self sealing plastic wrappings are in use that are applied with out coatings or under coatings.

Cathodic protection is often applied to both lines and to surface equipment. It is primarily applicable to the prevention of cathodic or the current transfer form of corrosion. Protection is provided by impressed current supplied by DC rectifier or natural galvanic cells, such as the magnesium anode.

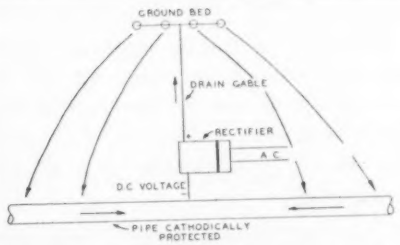


FIG. 1. Cathodic protection: Single rectifier and ground bed (anode).

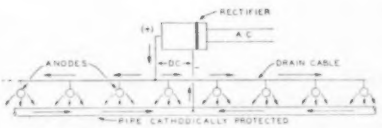


FIG. 2. Cathodic protection: Rectifier and distributed ground bed or anodes.

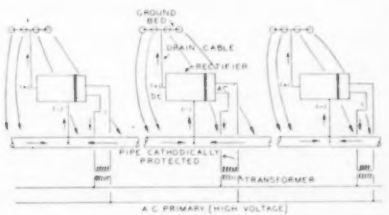


FIG. 3. Cathodic protection: Distributed rectifiers with single ground beds.

Considerations in Selection of Pipe-Protection Material

Twelve summary points of consideration in the selection of a material for underground pipe protection, viewed with respect to job requirements, are:

1. The material must adhere tenaciously to the pipe.
2. It should be non-absorbent and impervious to water, moisture vapor, etc.
3. It should possess good dielectric qualities.
4. It should be completely resistant to mineral acids, alkalies, salts, petroleum oils, and refined products such as gasoline and naphtha.
5. It should remain flexible at all temperatures.
6. Soil stress and pipe movement should not affect it.
7. Application should be simple, without unwieldly equipment, and preferably without heat and primer.
8. It should resist penetration by stones, wires, welding rod scraps, and other sharp materials found in the ditches and backfill.
9. It should be able to withstand rough handling without damage.
10. It should be quick setting and fast drying.
11. It should provide permanent protection to the pipe, yet not be prohibitive in cost.
12. The coating must be resistant and impervious to microorganism attack.

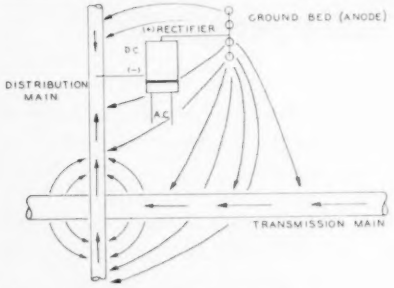


FIG. 4. Cathodic interference.

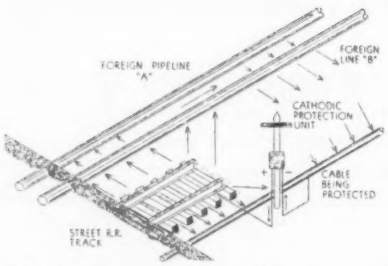


FIG. 5. Stray current corrosion.

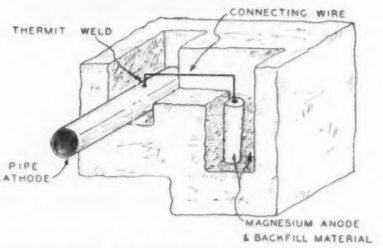


FIG. 6. Cathodic protection: Single anode installation.

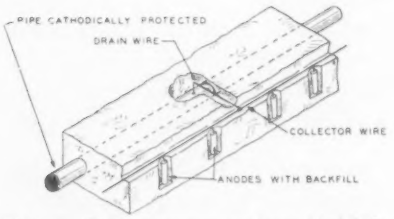


FIG. 7. Cathodic protection: Multiple anodes in series installation.

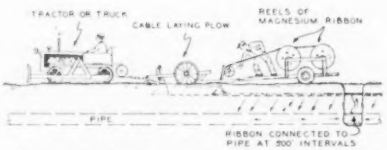


FIG. 8. Cathodic protection: Mangnesium ribbon installation.

Cathodic Protection

Although this method of protection is rather simple in principle, its application can become complicated, particularly if there are other underground structures in the same area. Technique of distributing the "impressed current" along the pipe line can be accomplished by many different methods. Typical wiring diagrams for some of these methods are shown in Figures 1, 2, and 3.

The cathodic system of protection is also susceptible to complications because of what is called "cathodic interference" (Fig. 4.). Suppose, for example, there is a high pressure line going through that portion of a distribution system in which it is desired to "impressed current." This high pressure line may also pick up current from the ground and carry it to some place where the high pressure line crosses over or goes near the distribution line. Then because the current has to get back to the power source, it will jump from the high pressure line to the ground to the distribution line. The short section of the high pressure lines becomes an anode. Every ampere of current leaving the pipe in this area will carry pipe wall metal with it, 20 pounds per ampere per year, and leakage in the high pressure line is inevitable.

The same sort of cathodic interference may be caused by reason of some other company installing "impressed current" protection for their system of cables or pipe lines as illustrated in Figure 5.

Where electrical power is available, selectively placed rectifiers and regulators are used in most applications. Where power is not available or locations are not easily maintained, the magnesium anode type of galvanic cell is most commonly used. Generating current in a similar way to a flash light battery, the anode is buried in soil which forms the cathode portion of the cell. In generating the electrical energy, the magnesium of the anode is consumed. Size of the magnesium anode, or ingot used is based on current requirements and the expected operating life of the pipe line or distribution system.

The ingots of magnesium used to create galvanic cells may be any one of a number of different sizes and weights. The sizes ordinarily used are 4, 8 12, 16, and 32 lb.

Still another type of magnesium anode is in the form of a ribbon about ⅜ in. x ¾ in. with a solid iron wire as a core.

Except for the ribbon type anodes, the magnesium is usually installed by digging a hole deep enough to put the ingot of magnesium about on a level with the pipe line, filling in around the magnesium with some sort of special "backfill." The purpose of the "backfill" is to provide better electrical efficiency for the magnesium.

Figures 6 and 7 show typical installations of magnesium ingots.

When the ribbon type magnesium anode is used, it is plowed under the surface of the ground and parallel to the pipe line. The pipe and ribbon are connected by insulated wire at intervals along the length of the installation. This continuous ribbon type anode is normally installed using a conventional cable laying plow (Figure 8).

Most installations of magnesium are designed so that the magnesium anodes will provide a small amount of current flowing onto each square foot of the pipe line and still have sufficient mass of magnesium to last at least 25 years

The type of anode installation to be made is a matter of choice to the corrosion engineer. The installation he selects will depend upon a number of factors such as the size of the pipe line, the number and activity of the galvanic cells existing along the pipe line, whether or not the soil offers very much resistance to the flow of electricity, and of course, how many years of life it is desired to add to the unprotected normal life of the line.

Measurement of pH in Soils and Water

It is important to understand what the term "pH" actually means. Briefly, pH is a measure of the acidity or alkalinity of a solution.

pH does measure the *strength* of an acid; it does not necessarily measure the amount of the acid. Weak acids such as acetic can be added in moderate amounts to a solution without radically affecting the acidity. Similar amounts of strong acids like sulfuric, when added to the same solution, will cause a large change in acidity. Strength or weakness of an acid depends upon the extent of dissociation, or ionization, of the acid to give hydrogen ions. The greater the ionization of the acid, the more the hydrogen ion activity and the greater the acidity of the solution.

The pH scale is a convenient logarithmic expression of the hydrogen ion concentration in terms of a normal solution. On this scale, 7 is neutral, while lower numbers indicate greater acidity and higher numbers, less acidity (greater alkalinity). For practical purposes the pH scale is considered as encompassing the ranges 0 to 14, since solutions with pH values above or below this range are rarely encountered. On the pH scale, a solution of pH 4 is ten times as acid as one of pH 5 and one-hundred times as acid as a solution of pH 6. A small error in pH value can mean a large error in acid activity. A pH of 7 is neutral or neither acid nor alkaline.

The two general methods for determining pH are the *colorimetric* and *electrometic* methods. The two operate on entirely different principles and have corresponding differences in utility and accuracy.

Careful consideration of each application is advisable before deciding upon a particular method of pH measurement. Equal consideration should also be given to future applications since the equipment for a given application may be of little value should requirements undergo a change.

Colorimetric pH Measurements

The colorimetric method for pH determination utilizes certain organic substances, called "indicators," which change color with change in pH. The simplest color pH test is by means of papers impregnated with indicator dye. These papers are subject to a number of errors, some of which are discussed below. Under favorable conditions, and in experienced hands, "long-range" indicating papers may give an accuracy of about one-half pH, and "short-range" papers, one quarter pH. In general, however, results with papers should be considered only approximations of actual hydrogen-ion concentration since important errors can occur under some conditions.

Colorimetric pH measurements made by adding solutions of individual indicators to the sample are based on the assumption that when equal quantities of an indicator are added to equal quantities of solutions which have the same pH value, identical colors will be produced. While this is not strictly true, colorimetric pH determinations are useful, providing proper care is taken in making each measurement.

If the colorimetric method is used with samples of unknown pH, it is advisable first to make an approximate determination so that the proper indicator can be selected. Each indicator has a range of about 1.5 pH, and, by using a variety of indicator sets, most of the pH range can be covered.

It is essential in making colorimetric measurements that the test tubes, pipettes, and other vessels used be kept scrupulously clean, and glassware, samples and indicator solutions be protected from fumes and dust. Care must also be taken to protect the colored "standards," such as paper, celluloid, glass, or liquid, against fading. Comparison of sample color against standards must be made under ordinary daylight. If this is not possible, special accessory illumination equipment should be employed to simulate daylight conditions since ordinary artificial light is not satisfactory.

Some limitations of the colorimetric method are apparent. The method depends upon acuteness of vision; cannot be adapted to continuous pH measurement or automatic pH control; requires a number of chemicals, racks and special glassware; is not useable in enclosed systems such as pipe lines. Additional difficulties are encountered especially in field measurements, notably that the colorimetric method is inapplicable to colored or turbid samples, often encountered in corrosion measurements.

It is also important to understand some of the method's less obvious limitations. It has been found that the addition of the indicator, actually a weak acid or weak base, changes the pH of the solution under test. In the case of slightly buffered or unbuffered solutions, this error can be a good fraction of a pH unit or more. Temperature errors are also encountered — phenolphthalein, for example, introduces an error of 0.15 pH per 10° C change. Other errors arise from specific adsorption effects in colloidal suspensions, from salt effects, dilution, dichromatism, hydrolysis, chlorination, etc.

In some cases, special equipment or techniques can be employed in an effort to eliminate or correct for these errors. Generally, however, complications occur and, especially where accuracy is a consideration, the electrometric method should be employed.

Electrometric pH Measurements

The electrometric method takes advantage of the fact that, with two electrodes in the solution, a voltage is developed at the electrode which is directly related to the pH. By amplifying and measuring this voltage, the pH of the solution can be read directly from a suitable meter scale. Modern pH meters employing the glass electrode operate in precisely this fashion.

Among the advantages of the electrometric method are greater versatility, accuracy and convenience of use. Measurements can be made under virtually all conditions of temperature, pressure, and composition of solution in the field as well as in the laboratory.

The two principal units required for electrometric determinations are the pH meter and an electrode pair. The electrode pair consists of a reference electrode, usually a calomel type, and a pH-sensitive electrode which can be one of several types.

One such type is the hydrogen electrode on which the pH scale is based. The hydrogen electrode, however, is not considered practical, since the use of hydrogen gas is inconvenient and the electrode is readily poisoned by many substances. Another pH-sensitive type is the quinhydrone electrode which, under favorable conditions, works rather well in the acid region. A third type is the antimony electrode which undergoes a change in potential more or less related to change in pH. All three types have at least one basic fault: in the presence of oxidizing or reducing substances in the sample, reactions occur at the electrodes which give rise to misleading results. The one electrode which is ideally suited for pH measurements is the glass electrode.

The performance of the glass electrode depends largely upon the type of glass from which the pH-sensitive immersion tip is made. In the past, most electrodes used thin bulbs of sodalime glass. A recently developed electrode uses general purpose glass, and the manufacturer claims it is superior because of its greater versatility. This new glass enables a single electrode to cover the temperature range from freezing to boiling as well as almost the entire pH range. The glass tip is so rugged that it can withstand considerable abrasion and even accidental impact against hard objects. Of special

interest for field use is the ability of this general purpose glass electrode to measure the pH of soil or surfaces which have only a trace of moisture. There is virtually no danger of breakage even if the electrode is thrust into the soil.

With ordinary electrode glasses, and to a lesser extent with general purpose glass, deviations from the actual pH occur in high pH solutions containing high concentrations of sodium ions. Sodium-ion errors can either be compensated for by adding corrections obtained from a chart, or eliminated by using glass electrodes made from either amber glass or type "E" glass. Amber glass is recommended by one manufacturer for high-temperature measurements at any pH, even in boiling solutions of high acidity or alkalinity.

The pH Meter

pH Meters are available for every set of requirements. For portable field use, instruments are available which carry the necessary items for pH measurement within its case. These are simple to operate and withstand even rough handling. For the laboratory, battery-operated and a-c operated pH meters are available. Continuous fully-automatic pH recording and control of process solutions in pipelines, vats and tanks is made possible by the large, line-operated pH indicators.

Actual operation of some makes of pH instruments has been considerably simplified. With the electrodes in the sample, all that is necessary to make a measurement in a series is to move the knob or push button, and the pH reading appears directly on a dial or meter. With these modern instruments, standardization requires only a single buffer check. Temperature compensation is generally built into the meter, and no calculations are required. One manufacturer supplies an internally-shielded glass electrode with a continuous, shielded cable and has eliminated the otherwise-serious effects of electrostatic interference, so that accurate measurements can be made even in the presence of powerful electrical machinery. Maintenance consists merely of occasional addition of saturated KCI solution to the reference electrode; newly designed glass electrodes are entirely factory-sealed.

Adapted from—Reference Book on Instruments.
Issued by—American Gas Association.

Nipple-and-Can Test of Soil Corrosivity

In the nipple-and-can method the soil corrosivity is determined by the loss in weight of a steel nipple that is immersed in the nearly water-saturated soil and subjected to electrolysis under a potential two volts for 24 hours.

The nipples used are 4″ unthreaded lengths of ½″ stock black pipe which are cleaned by sandblasting, and identified by letters or numbers stamped near one end. Used nipples may be sandblasted and used again. All foreign material such as rust, paint, grease or dirt is removed with a wire brush or a suitable solvent, such as benzene or carbon tetrachloride. After sandblasting the nipples are wire-brushed to remove any particles of sand adhering to them. The nipples are then weighed, the weight being determined in *grams to the first decimal.*

The soil sample is crushed with mortar and pestle, if necessary, and all extraneous matter, such as plant roots, leaves, wood, paper and asphalt, is removed. Samples containing excess water are air dried. Do not drain off any excess water.

A one-pint friction top can, 4″ deep by 3¼″ diameter, with cover and top rim removed is used as a container, and also serves as the cathode of the test cell. It may be used over and over until it corrodes through, as long as it is thoroughly scrubbed with a brush and hot water between each test.

The test cell is assembled by inserting a No. 1 rubber stopper in the unidentified end of a nipple leaving ½″ protruding, and placing this assembly in the center of the can with the stoppered end down, the stopper serving as an insulator. A cork stopper is placed in the upper end of the nipple to prevent any soil getting inside the nipple. Soil and distilled water in the correct proportions to bring the soil slightly below the saturation point are placed in the can around the nipple, filling the can nearly to the top. More water may be added later if the soil dries out, as it is important that the soil remain at least 50% sautrated throughout the test. Soils that do not readily absorb water may be mixed before placing in the can.

The cork stopper is removed from the nipple, and the nipple is connected to the positive terminal of a two-volt storage battery, making it the anode. The negative terminal of the battery is connected to the can. After a period of 24 hours the battery is disconnected, the nipple is removed and immediately washed in warm tap water, steel wool being used to remove the soil and heavier corrosion products if necessary, and then placed in a boiling 2% solution of ammonium citrate until thoroughly clean. The nipple is then washed with boiling water, air dried, and weighed. The loss in weight is reported as the nipple-and-can corrosion index.

Where a large number of tests are to be made it is convenient to assemble a number of cans, such as twelve, in a wooden rack, the cans being soldered to copper or brass strips mounted on removable shelves, the strips being connected to the negative terminal of the battery. Wires are mounted on the under side of the shelves, to which are connected flexible wires terminating in battery clips, which may be fastened to the nipples. These wires are connected to the positive terminal of the battery through a time switch, which may be set for the required 24-hour period. This allows tests to be run over the weekend, and eliminate the human element in timing the test. No. appreciable error is introduced by allowing the nipples to remain in the soil for a day after the current is shut off.

Classification of Soils

The following classification has been arbitrarily chosen as satisfactory.

Corrosion index	*Types of soil*	*Soil ma p Color code*
0.0 to 0.5	A — Good	Green
0.5 to 0.75	B — Fair	Yellow
0.75 to 1.5	C — Bad	Brown
1.5 and over	D — Very bad	Red

This method has been used extensively and appears to be satisfactory for the types of soils occurring in California and other areas where the soils are alkaline. There are few checks on the reliability of the method when applied to the acid soils of the East. Some of the advantages of the test are ease of manipulation, speed (many tests may be run at the same time), and the extensive correlation that has been obtained with field experience. Some of the objections to the test are that the applied voltage is greater that that occurring in soil corrosion, and that the loss of weight is caused by and is proportional to the current flowing. The current is determined by both the soil resistance and polarization. However, it has been shown that similar data are obtained when six volts is used, and the decrease in current due to polarization seems to be a characteristic of the particular soil.

Adapted from—Reference Book on Instruments.
Issued by—American Gas Association.

How To Compute Flow of Gas Through Orifice Meters

Table and figure numbers given here are the same as given in 'Gas Measurement Committee Report, No. 2, American Gas Association, from which these data were taken.—Editor.

General Equation

In the measurement of most gases, and especially natural gas, it is almost the universal practice (in the United States) to express the flow in cubic feet per hour referred to some specified reference or base condition of pressure and temperature. For the calculation of the quantity of gas the committee* recommends the continued use of the formula:

$$Q_h = C' \sqrt{h_w p_f} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which

Q_h = Quantity rate of flow at base conditions, ft³/hr.

C' = Orifice flow constant.

h_w = Differential pressure in inches of water.

p_f = Absolute static pressure in lbs/sq in.

Orifice Flow Constant

The orifice flow constant, C′, may be defined as the rate of flow, in cu. ft. per hour, at base conditions, when the extension, $\sqrt{h_w p_f}$ equals one. It was formerly known as the "flow coefficient." It is here called "orifice flow constant." It is to be calculated by the following equation:

$$C' = F_b \times F_r \times Y \times F_{pb} \times F_{tb} \times F_{tf} \times F_g \times F_{pv} \quad (2)$$

in which

F_b = Basic orifice flow factor

F_r = Reynolds' number factor

Y = Expansion factor

F_{pb} = Pressure base factor

F_{tb} = Temperature base factor

F_{tf} = Flowing temperature factor

F_g = Specific gravity factor

F_{pv} = Supercompressibility factor

It will be noted that all of the factors used in calculating the orifice flow constants are familiar except F_r, F_b, Y and F_{pv}.

The values of all the factors F_b, F_r, etc., are obtained from the tables. The following method is for a meter with flange taps. The method for a meter with pipe taps will be exactly the same, except that the tables for pipe taps will be used.

Basic Orifice Flow Factor

The basic orifice flow factor, F_b, is taken directly from Table 4, for the correct orifice and pipe size. For sizes not listed in this table, the value of F_b may be found by calculation as explained Appendix B of this report. (Interpolation should not be relied upon). The pipe diameter of the orifice sections, it is important to point out, should be within the limits specified in Table 2. If the value of D_1 is outside of those limits the flow factors of Table 4 cannot be relied upon. Then the exact value of F_b should be calculated, for the particular value of "β" based on the actual value of D_1.

Orifice to Pipe Diameter	Recommended Maximum Allowable Tolerance between Measured Inside Diameter of the upstream section of the meter run, and the Published "Approximate Internal Diameter", which was used in Computing Basic Orifice Constants of this Report.	
Ratio "β"	Flange Taps	Pipe Taps
.10 to .25	5.0%	3.5%
.25 to .35	3.0%	2.0%
.35 to .45	2.0%	1.0%
.45 to .55	1.5%	0.6%
.55 to .65	1.0%	0.3%
.65 to .75	0.5%	0.2%

Reynolds' Number Factor

The Reynolds' number factor, F_r, is taken from Table 6. For its determination the average extension at which the meter operates must be known in addition to the orifice and pipe size.

The value of $\sqrt{h_w p_f}$ (extension) used in selecting the F_r factor from Table 6 may be based upon the meter record, or estimated from a knowledge of the average static pressure and the average differential at which the meter may operate. This extension, it should be noted, is an index with which a factor is selected, and does not enter directly into the computations. An extension value selected as suggested will probably be sufficiently close to the average operating conditions of the meter for selecting the proper value of F_r, especially since the variations in F_r corresponding to values of $\sqrt{h_w p_f}$ above or below the selected average will be compensating (plus or minus) over any appreciable length of time.

The tables, it should be noted, have been calculated by using average values of viscosity, 0.0000069 Lb/ft-sec, of temperature, 520° F. absolute, and of gravity, 0.65, applying particularly to natural gas. If the gas being metered has a viscosity, temperature or gravity quite different from these, the value of F_r in Table 6 may not be applicable. However, for variations in viscosity from .0000059 to .0000079, in temperatures of from 490° to 550° F. absolute, or in specific gravity of from .55 to .75, the variations in the factor F_r would be well within the tolerances given for this report.

Expansion Factor

The expansion factor, Y, is to be taken from Tables 8, 9, or 10, depending upon the tap location from which the static pressure is taken. Here the ratio h_w/p_f is an index with which the value of Y is selected, and may be based upon the meter record, or estimated from the average static pressure and the differential at which the meter may operate. The effects of operating variations from this "average" h_w/p_f will ordinarily be compensating.

For meters with flange connections, the variations to be expected in meter accuracy from the average will be greater or less depending on whether upstream, downstream or in-

*From the Gas Measurement Committee Report, American Gas Association.

termediate pressure connections are used. As the h/p ratio in increased, it will be observed, the use of the intermediate static pressure gives the minimum departure from the mean condition used in the selection of the expansion factor.

With orifice meters using "pipe taps" the variation from the mean estimated operating value of h/p used in the determination of the expansion factor (Y) result in the greatest variation in the value of Y when upstream static pressures are used. The use of intermediate static pressures in connection with pipe taps has little advantage, since it only slightly reduces the variations in Y resulting from departures from the mean. The use of downstream static pressures for this type of connection results in the least change in the values of Y due to changes in the values of the h/p ratio from the mean operating value.

Note — In use it may be found that a group of meters in the same locality, or operating under the same conditions, will have the same values for F_r, and Y. If this is true the flow constants in this group will be the same for all plates of the same size and ratio.

Pressure Base Factor

The pressure base factor, F_{pb}, is taken from Table 13.

Temperature Base Factor

The temperature base factor, F_{tb}, is taken from Table 14.

Flowing Temperature Factor

The flowing temperature factor, F_{tf}, is taken from Table 15, and should be based on the actual flowing temperature of the gas.

Specific Gravity Factor

The specific gravity factor, F_g, is taken from Table 16, and should be based on the actual specific gravity of the gas as determined by test, and the portion of table nearest to this used, with linear interpolation if necessary.

Application and Examples

In the application of these factors, it will be noted that F_r, Y, F_{pb}, F_{tf}, F_g and F_{pv} are multipliers, and may be applied either to the basic orifice flow factor, F_b, or to the calculated quantity rate of flow, as preferred.

Examples of the calculation of the quantity rate of flow for various conditions, using the tables in this report follows:

Example 1.

Given:

D_1 = Line size = 8″ Nominal inside diameter = 8.071″ actual inside diameter.

D_2 = Orifice size = 1.000″.

Meter equipped with Flange Taps, with static pressure from downstream tap.

T_f = Flowing temperature = 65 F.

P_b = 4 oz above 14.4 lb/sq in. = 14.65 lb/sq in. absolute = pressure base.

T_b = Temperature base = 50 F = 510 absolute.

Specific gravity = .570.

Average differential head h_w = 50″ water.

Average downstream static pressure, p_f = 40 lb/sq in. absolute.

Supercompressibility ratio (by test), N = 0.004.

Required:

The orifice flow constant and the quantity rate of flow for one hour at base conditions.

$$\beta = \frac{D_2}{D_1} = .1239$$

Published approximate inside diameter of pipe = 8.071.
Ratio actual inside diameter to approximate inside diameter = 1.000.

Per cent difference = 0.0 therefore tables can be used.

Average $\sqrt{h_w p_f} = 44.72$

Average $\dfrac{h_w}{p_f} = 1.25$

From Table 4 for 1″ plate in 8″ line:
$F_b = 204.97$

From Table 6, 8″ line 1″ plate

for $\sqrt{h_w p_f} = 40$ $F_r = 1.0017$

$\sqrt{h_w p_f} = 50$ $F_r = 1.0014$

then at $\sqrt{h_w p_f} = 44.72$ $F_r = 1.0015$

From Table 9 (Y_2 for downstream static pressure)

at $\dfrac{h_w}{p_f} = 1.2$ and $\beta = .1$ and .2; $Y_2 = 1.0080$

at $\dfrac{h_w}{p_f} = 1.3$ and $\beta = .1$ and .2; $Y_2 = 1.0087$

Interpolating for

$\dfrac{h_w}{p_f} = 1.25$ and $\beta = .1239$; $Y_2 = 1.0084$

From Table 13
for 4 oz above 14.4 lb/sq in.; $F_{pb} = .9829$

From Table 14
for $T_b = 50$ F; $F_{tb} = .9808$

From Table 15
for $T_f = 65$ F; $F_{tf} = .9952$

From Table 16
for Specific Gravity = .570; $F_g = 1.3245$

From Table 17
for N = .004 $F_{pv} = 1.002$

Then the orifice flow constant is:

$C' = 204.97 \times 1.0015 \times 1.0088 \times .9829 \times .9808 \times .9952 \times 1.3245 + 1.0020 = 263.65$ = Orifice Flow Constant

and the rate of flow for 1 hour at base conditions is:

$Q_h = 263.65 \sqrt{50 \times 40} = 11791$

The same value of Q_h is obtained if the computations are made in this order:

$Q_h = [204.97 \times \sqrt{50 \times 40}] \times (1.0015 \times 1.0088 \times 0.9829 \times 0.9808 \times 0.9952 \times 1.3245 \times 1.0020) = 9166.5 \times 1.2863 = 11791$

The tolerances necessary in the use of any orifice meter do not warrant taking the values in these tables to be accurate beyond one in 500. Four figures are given in all cases solely to enable different computers to agree within 1 or 2 in the fourth significant figure regardless of whether it is on the right or left of the decimal.

In some of the tables values of the constants for a few of the smaller orifices are marked with an asterisk, these orifices have diameter ratios lower than the minimum value for which the formulas used were derived and this size of plate should not be used unless it is understood that the accuracy of measurement will be relatively low.

In preparing these tables the intermediate steps were usually carried out to 5 or 6 figures and the final value rounded off to the nearest fourth or fifth figure. When the fifth or sixth figure was a "5" the fourth or fifth figure was taken as the nearest *even* number.

TABLE 4 F_b BASIC ORIFICE FACTORS — FLANGE TAPS

Base Temperature = 60° F. Flowing Temperature = 60° F; $\sqrt{h_w p_f} = \infty$
Base Pressure = 14.4 Lb./Sq. in. abs; Specific Gravity = 1.0; $h_w/p_f = 0$

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter Inches	2" Std. 2.067	3" Std. 3.068	4" Std. 4.026	6" Std. 6.065	8" Std. 8.071	10" Std. 10.136	12" Std. 12.090	15¼" Std. 15.25
.250	13.002	12.996*	12.974*					
.375	29.079	29.026	28.989*					
.500	51.680	51.444	51.376	51.328*				
.625	81.129	80.426	80.218	80.080				
.750	117.77	116.16	115.67	115.30				
.875	162.11	158.70	157.81	157.08	156.82			
1.000	215.04	208.21	206.62	205.45	204.97			
1.125	277.93	264.97	262.21	260.39	259.69	259.27		
1.250	353.04	329.41	324.72	321.93	320.94	320.35	320.00	
1.375	443.44	402.10	394.35	390.11	388.73	387.95	387.47	
1.500	554.71	483.80	471.35	464.98	463.10	462.07	461.44	
1.625		575.47	556.06	546.62	544.07	542.73	541.93	541.06
1.750		678.61	648.93	635.11	631.64	629.94	628.93	627.85
1.875		794.99	750.50	730.55	725.90	723.73	722.48	721.15
2.000		926.76	861.42	833.06	826.86	824.11	822.56	820.95
2.125		1076.6	982.50	942.83	934.59	931.10	929.21	927.26
2.250		1251.2	1114.9	1060.0	1049.1	1044.7	1042.4	1040.1
2.375			1259.9	1184.9	1170.5	1165.1	1162.3	1159.5
2.500			1419.0	1317.7	1299.0	1292.1	1288.7	1285.4
2.625			1593.9	1458.7	1434.4	1425.8	1421.7	1417.9
2.750			1786.7	1608.3	1577.1	1566.4	1561.5	1557.0
2.875			2000.3	1767.0	1727.1	1713.8	1707.9	1702.6
3.000			2245.3	1935.2	1884.6	1868.2	1861.0	1854.9
3.125				2113.4	2049.7	2029.5	2020.9	2013.7
3.250				2302.4	2222.7	2197.8	2187.6	2179.2
3.375				2502.8	2403.7	2373.4	2361.1	2351.3
3.500				2715.7	2593.1	2556.1	2541.5	2530.1
3.625				2941.9	2791.1	2746.2	2728.9	2715.6
3.750				3182.5	2998.0	2943.8	2923.2	2907.9
3.875				3438.5	3214.2	3149.1	3124.6	3106.8
4.000				3711.4	3439.9	3362.1	3333.1	3312.5
4.250				4313.2	3922.0	3812.1	3772.0	3744.4
4.500				5013.1	4448.7	4295.5	4240.5	4203.8
4.750					5024.8	4812.8	4739.6	4691.2
5.000					5656.2	5369.9	5270.4	5206.7
5.250					6349.6	5965.5	5834.0	5751.2
5.500					7112.9	6604.3	6432.1	6324.8
5.750					7956.0	7289.8	7066.1	6928.6
6.000					8906.5	8026.3	7738.1	7563.0
6.250						8818.7	8450.0	8229.2
6.500						9672.0	9204.9	8927.9
6.750						10592	10006	9660.4
7.000						11587	10856	10428
7.250						12664	11759	11231
7.500						13851	12719	12073
7.750							13741	12954
8.000							14830	13877
8.250							15991	14843
8.500							17231	15856
8.750							18564	16918
9.000							20014	18031
9.250								19198
9.500								20426
9.750								21715
10.000								23070
10.250								24496
10.500								25997
10.750								27578
11.000								29253
11.250								31042

TABLE 6
F_r
REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 2" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$ 4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.250	1.0232	1.0206	1.0185	1.0168	1.0154	1.0132	1.0116	1.0093	1.0077	1.0062	1.0046	1.0037	1.0031	1.0026	1.0023	1.0019	1.0013	1.0009	1.0005
.375	1.0181	1.0161	1.0145	1.0132	1.0121	1.0104	1.0091	1.0073	1.0060	1.0048	1.0036	1.0029	1.0024	1.0021	1.0018	1.0015	1.0010	1.0007	1.0004
.500	1.0147	1.0131	1.0118	1.0107	1.0098	1.0084	1.0073	1.0059	1.0049	1.0039	1.0029	1.0024	1.0020	1.0017	1.0015	1.0012	1.0008	1.0006	1.0003
.625	1.0126	1.0112	1.0101	1.0092	1.0084	1.0072	1.0063	1.0051	1.0042	1.0034	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
.750	1.0118	1.0105	1.0094	1.0086	1.0079	1.0067	1.0059	1.0047	1.0039	1.0031	1.0024	1.0019	1.0016	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
.875	1.0119	1.0106	1.0095	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.000	1.0129	1.0114	1.0103	1.0094	1.0086	1.0074	1.0064	1.0052	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.125	1.0144	1.0128	1.0115	1.0104	1.0096	1.0082	1.0072	1.0057	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.250	1.0161	1.0143	1.0129	1.0117	1.0108	1.0092	1.0081	1.0065	1.0054	1.0043	1.0032	1.0026	1.0022	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.375	1.0179	1.0159	1.0143	1.0130	1.0119	1.0102	1.0089	1.0072	1.0060	1.0048	1.0036	1.0029	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
1.500	1.0193	1.0172	1.0155	1.0141	1.0129	1.0110	1.0097	1.0077	1.0064	1.0052	1.0039	1.0031	1.0026	1.0022	1.0019	1.0015	1.0011	1.0008	1.0004

For 4" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$ 4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.250	1.0264	1.0234	1.0211	1.0192	1.0176	1.0151	1.0132	1.0105	1.0088	1.0070	1.0053	1.0042	1.0035	1.0030	1.0026	1.0021	1.0015	1.0011	1.0005
.375	1.0227	1.0202	1.0181	1.0165	1.0151	1.0130	1.0113	1.0091	1.0076	1.0060	1.0045	1.0036	1.0030	1.0026	1.0023	1.0018	1.0013	1.0009	1.0005
.500	1.0195	1.0173	1.0156	1.0142	1.0130	1.0111	1.0097	1.0078	1.0065	1.0052	1.0039	1.0031	1.0026	1.0022	1.0019	1.0016	1.0011	1.0008	1.0004
.625	1.0167	1.0149	1.0134	1.0122	1.0112	1.0096	1.0084	1.0067	1.0056	1.0045	1.0033	1.0027	1.0022	1.0019	1.0017	1.0013	1.0010	1.0007	1.0003
.750	1.0144	1.0128	1.0116	1.0105	1.0096	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
.875	1.0126	1.0112	1.0100	1.0091	1.0084	1.0072	1.0063	1.0050	1.0042	1.0033	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
1.000	1.0110	1.0098	1.0088	1.0080	1.0074	1.0063	1.0055	1.0044	1.0037	1.0029	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
1.125	1.0099	1.0088	1.0079	1.0072	1.0066	1.0057	1.0050	1.0040	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
1.250	1.0091	1.0081	1.0073	1.0066	1.0061	1.0052	1.0046	1.0036	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
1.375	1.0086	1.0077	1.0069	1.0063	1.0057	1.0049	1.0043	1.0034	1.0029	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
1.500	1.0084	1.0075	1.0067	1.0061	1.0056	1.0048	1.0042	1.0034	1.0028	1.0022	1.0017	1.0013	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
1.625	1.0085	1.0075	1.0068	1.0062	1.0056	1.0048	1.0042	1.0034	1.0028	1.0023	1.0017	1.0014	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
1.750	1.0088	1.0078	1.0070	1.0064	1.0058	1.0050	1.0044	1.0035	1.0029	1.0023	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
1.875	1.0092	1.0082	1.0074	1.0067	1.0062	1.0053	1.0046	1.0037	1.0031	1.0025	1.0018	1.0015	1.0012	1.0011	1.0009	1.0007	1.0005	1.0004	1.0002
2.000	1.0099	1.0088	1.0079	1.0072	1.0066	1.0057	1.0049	1.0040	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
2.125	1.0107	1.0095	1.0085	1.0078	1.0071	1.0061	1.0053	1.0043	1.0036	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
2.250	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
2.375	1.0125	1.0111	1.0100	1.0091	1.0084	1.0072	1.0063	1.0050	1.0042	1.0033	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
2.500	1.0135	1.0120	1.0108	1.0098	1.0090	1.0077	1.0068	1.0054	1.0045	1.0036	1.0027	1.0022	1.0018	1.0015	1.0014	1.0011	1.0008	1.0005	1.0003
2.625	1.0145	1.0129	1.0116	1.0105	1.0096	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
2.750	1.0154	1.0137	1.0123	1.0112	1.0103	1.0088	1.0077	1.0062	1.0051	1.0041	1.0031	1.0025	1.0021	1.0018	1.0015	1.0012	1.0009	1.0006	1.0003
2.875	1.0162	1.0144	1.0130	1.0118	1.0108	1.0093	1.0081	1.0065	1.0054	1.0043	1.0032	1.0026	1.0022	1.0019	1.0016	1.0013	1.0009	1.0006	1.0003
3.000	1.0168	1.0150	1.0135	1.0123	1.0112	1.0096	1.0084	1.0067	1.0056	1.0045	1.0034	1.0027	1.0022	1.0019	1.0017	1.0013	1.0010	1.0007	1.0003

For 6" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$ 4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.500	1.0223	1.0198	1.0178	1.0162	1.0149	1.0127	1.0112	1.0089	1.0074	1.0059	1.0045	1.0036	1.0030	1.0025	1.0022	1.0018	1.0013	1.0009	1.0004
.625	1.0200	1.0178	1.0160	1.0146	1.0134	1.0114	1.0100	1.0080	1.0067	1.0053	1.0040	1.0032	1.0027	1.0023	1.0020	1.0016	1.0011	1.0008	1.0004
.750	1.0178	1.0158	1.0142	1.0129	1.0118	1.0101	1.0089	1.0071	1.0059	1.0047	1.0036	1.0028	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
.875	1.0161	1.0143	1.0129	1.0117	1.0107	1.0092	1.0080	1.0064	1.0054	1.0043	1.0032	1.0026	1.0021	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.000	1.0144	1.0128	1.0115	1.0105	1.0096	1.0082	1.0072	1.0058	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0012	1.0008	1.0006	1.0003
1.125	1.0129	1.0115	1.0103	1.0094	1.0086	1.0074	1.0065	1.0052	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.250	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
1.375	1.0105	1.0093	1.0084	1.0076	1.0070	1.0060	1.0052	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
1.500	1.0095	1.0085	1.0076	1.0069	1.0063	1.0054	1.0048	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0005	1.0004	1.0002
1.625	1.0087	1.0077	1.0070	1.0063	1.0058	1.0050	1.0044	1.0035	1.0029	1.0023	1.0017	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
1.750	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0040	1.0032	1.0027	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
1.875	1.0076	1.0067	1.0060	1.0055	1.0050	1.0043	1.0038	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
2.000	1.0072	1.0064	1.0058	1.0052	1.0048	1.0041	1.0036	1.0029	1.0024	1.0019	1.0014	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.125	1.0070	1.0062	1.0056	1.0051	1.0046	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.250	1.0068	1.0061	1.0055	1.0050	1.0046	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.375	1.0069	1.0061	1.0055	1.0050	1.0046	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.500	1.0070	1.0062	1.0056	1.0051	1.0046	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.625	1.0072	1.0064	1.0057	1.0052	1.0048	1.0041	1.0036	1.0029	1.0024	1.0019	1.0014	1.0011	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.750	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0007	1.0006	1.0004	1.0003	1.0901
2.875	1.0079	1.0070	1.0063	1.0057	1.0052	1.0045	1.0039	1.0031	1.0026	1.0021	1.0016	1.0013	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
3.000	1.0083	1.0074	1.0066	1.0060	1.0055	1.0047	1.0042	1.0033	1.0028	1.0022	1.0017	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
3.125	1.0088	1.0078	1.0071	1.0064	1.0059	1.0050	1.0044	1.0035	1.0029	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
3.250	1.0094	1.0084	1.0075	1.0068	1.0063	1.0054	1.0047	1.0038	1.0031	1.0025	1.0019	1.0015	1.0013	1.0011	1.0009	1.0008	1.0005	1.0004	1.0002
3.375	1.0100	1.0089	1.0080	1.0073	1.0067	1.0057	1.0050	1.0040	1.0033	1.0027	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
3.500	1.0106	1.0095	1.0085	1.0077	1.0071	1.0061	1.0053	1.0043	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
3.625	1.0113	1.0100	1.0090	1.0082	1.0075	1.0065	1.0056	1.0045	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0005	1.0002
3.750	1.0120	1.0106	1.0096	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
3.875	1.0126	1.0112	1.0101	1.0092	1.0084	1.0072	1.0063	1.0050	1.0042	1.0034	1.0025	1.0020	1.0017	1.0014	1.0013	1.0010	1.0007	1.0005	1.0003
4.000	1.0133	1.0118	1.0106	1.0097	1.0089	1.0076	1.0066	1.0053	1.0044	1.0035	1.0027	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
4.250	1.0145	1.0129	1.0116	1.0105	1.0097	1.0083	1.0072	1.0058	1.0048	1.0039	1.0029	1.0023	1.0019	1.0017	1.0014	1.0012	1.0008	1.0006	1.0003
4.500	1.0155	1.0138	1.0124	1.0113	1.0103	1.0088	1.0077	1.0062	1.0052	1.0041	1.0031	1.0025	1.0021	1.0018	1.0015	1.0012	1.0009	1.0006	1.0003

TABLE 6 — Continued

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REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 8" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
.875	1.0185	1.0165	1.0148	1.0135	1.0124	1.0106	1.0093	1.0074	1.0062	1.0049	1.0037	1.0030	1.0025	1.0021	1.0019	1.0015	1.0011	1.0007	1.0004
1.000	1.0170	1.0151	1.0136	1.0124	1.0113	1.0097	1.0085	1.0068	1.0057	1.0045	1.0034	1.0027	1.0023	1.0019	1.0017	1.0014	1.0010	1.0007	1.0003
1.125	1.0156	1.0138	1.0125	1.0113	1.0104	1.0089	1.0078	1.0062	1.0052	1.0042	1.0031	1.0025	1.0021	1.0018	1.0016	1.0012	1.0009	1.0006	1.0003
1.250	1.0143	1.0127	1.0114	1.0104	1.0095	1.0082	1.0071	1.0057	1.0048	1.0038	1.0029	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.375	1.0131	1.0116	1.0105	1.0095	1.0087	1.0075	1.0065	1.0052	1.0044	1.0035	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
1.500	1.0120	1.0106	1.0096	1.0087	1.0080	1.0068	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.625	1.0110	1.0098	1.0088	1.0080	1.0073	1.0063	1.0055	1.0044	1.0037	1.0029	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
1.750	1.0101	1.0090	1.0081	1.0073	1.0067	1.0058	1.0050	1.0040	1.0034	1.0027	1.0020	1.0016	1.0013	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
1.875	1.0093	1.0082	1.0074	1.0067	1.0062	1.0053	1.0046	1.0037	1.0031	1.0025	1.0019	1.0015	1.0012	1.0011	1.0009	1.0007	1.0005	1.0004	1.0002
2.000	1.0086	1.0076	1.0069	1.0062	1.0057	1.0049	1.0043	1.0034	1.0029	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
2.125	1.0080	1.0071	1.0064	1.0058	1.0053	1.0045	1.0040	1.0032	1.0027	1.0021	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
2.250	1.0074	1.0066	1.0059	1.0054	1.0050	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0002
2.375	1.0070	1.0062	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.500	1.0066	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0026	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
2.625	1.0064	1.0056	1.0051	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
2.750	1.0061	1.0055	1.0049	1.0045	1.0041	1.0035	1.0031	1.0025	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0002	1.0001
2.875	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.00[illegible]	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.000	1.0059	1.0053	1.0047	1.0043	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.00[illegible]	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.125	1.0059	1.0053	1.0047	1.0043	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.250	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.375	1.0061	1.0054	1.0049	1.0044	1.0041	1.0035	1.0031	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.500	1.0063	1.0056	1.0050	1.0046	1.0042	1.0036	1.0031	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.625	1.0065	1.0058	1.0052	1.0047	1.0043	1.0037	1.0033	1.0026	1.0022	1.0017	1.0013	1.0010	1.0009	1.0007	1.0007	1.0005	1.0004	1.0003	1.0001
3.750	1.0068	1.0060	1.0054	1.0049	1.0045	1.0039	1.0034	1.0027	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.875	1.0071	1.0063	1.0057	1.0051	1.0047	1.0040	1.0035	1.0028	1.0024	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
4.000	1.0074	1.0066	1.0060	1.0054	1.0050	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
4.250	1.0082	1.0073	1.0066	1.0060	1.0055	1.0047	1.0041	1.0033	1.0028	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
4.500	1.0091	1.0081	1.0073	1.0067	1.0061	1.0052	1.0046	1.0037	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
4.750	1.0101	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
5.000	1.0112	1.0099	1.0089	1.0081	1.0074	1.0064	1.0056	1.0045	1.0037	1.0030	1.0022	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0004	1.0002
5.250	1.0122	1.0108	1.0097	1.0089	1.0081	1.0070	1.0061	1.0049	1.0041	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
5.500	1.0131	1.0117	1.0105	1.0095	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
5.750	1.0140	1.0124	1.0112	1.0102	1.0093	1.0080	1.0070	1.0056	1.0047	1.0037	1.0028	1.0022	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
6.000	1.0147	1.0131	1.0118	1.0107	1.0098	1.0084	1.0074	1.0059	1.0049	1.0039	1.0029	1.0024	1.0020	1.0017	1.0015	1.0012	1.0008	1.0006	1.0003

For 10" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
1.125	1.0176	1.0157	1.0141	1.0128	1.0118	1.0101	1.0088	1.0071	1.0059	1.0047	1.0035	1.0028	1.0024	1.0020	1.0018	1.0014	1.0010	1.0007	1.0004
1.250	1.0164	1.0146	1.0131	1.0119	1.0109	1.0094	1.0082	1.0066	1.0055	1.0044	1.0033	1.0026	1.0022	1.0019	1.0016	1.0013	1.0009	1.0007	1.0003
1.375	1.0153	1.0136	1.0122	1.0111	1.0102	1.0087	1.0076	1.0061	1.0051	1.0041	1.0031	1.0024	1.0020	1.0017	1.0015	1.0012	1.0009	1.0006	1.0003
1.500	1.0142	1.0126	1.0114	1.0103	1.0095	1.0081	1.0071	1.0057	1.0047	1.0038	1.0028	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.625	1.0132	1.0117	1.0106	1.0096	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
1.750	1.0122	1.0109	1.0098	1.0089	1.0082	1.0070	1.0061	1.0049	1.0041	1.0033	1.0024	1.0020	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
1.875	1.0114	1.0101	1.0091	1.0083	1.0076	1.0065	1.0057	1.0046	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0007	1.0005	1.0002
2.000	1.0106	1.0094	1.0085	1.0077	1.0071	1.0060	1.0053	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0011	1.0008	1.0006	1.0004	1.0002
2.125	1.0098	1.0087	1.0079	1.0072	1.0066	1.0056	1.0049	1.0039	1.0033	1.0026	1.0020	1.0016	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
2.250	1.0091	1.0081	1.0073	1.0067	1.0061	1.0052	1.0046	1.0037	1.0030	1.0024	1.0018	1.0015	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
2.375	1.0085	1.0076	1.0068	1.0062	1.0057	1.0049	1.0043	1.0034	1.0028	1.0023	1.0017	1.0014	1.0011	1.0010	1.0009	1.0007	1.0005	1.0003	1.0002
2.500	1.0080	1.0071	1.0064	1.0058	1.0053	1.0046	1.0040	1.0032	1.0027	1.0021	1.0016	1.0013	1.0011	1.0039	1.0008	1.0006	1.0005	1.0003	1.0002
2.625	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0001
2.750	1.0070	1.0062	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
2.875	1.0066	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0027	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.000	1.0063	1.0056	1.0050	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.125	1.0060	1.0053	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.250	1.0058	1.0051	1.0046	1.0042	1.0039	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.375	1.0056	1.0050	1.0045	1.0041	1.0037	1.0032	1.0028	1.0022	1.0019	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
3.500	1.0054	1.0048	1.0044	1.0040	1.0036	1.0031	1.0027	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.625	1.0054	1.0048	1.0043	1.0039	1.0036	1.0031	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.750	1.0053	1.0047	1.0042	1.0039	1.0035	1.0030	1.0026	1.0021	1.0018	1.0014	1.0011	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
3.875	1.0053	1.0047	1.0042	1.0038	1.0035	1.0030	1.0026	1.0021	1.0018	1.0014	1.0011	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.000	1.0053	1.0047	1.0043	1.0039	1.0035	1.0030	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.250	1.0055	1.0049	1.0044	1.0040	1.0037	1.0031	1.0027	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
4.500	1.0058	1.0051	1.0046	1.0042	1.0039	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
4.750	1.0062	1.0055	1.0050	1.0045	1.0041	1.0035	1.0031	1.0025	1.0021	1.0017	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0002	1.0001
5.000	1.0068	1.0060	1.0054	1.0049	1.0045	1.0039	1.0034	1.0027	1.0022	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
5.250	1.0074	1.0066	1.0059	1.0054	1.0049	1.0042	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0038	1.0007	1.0006	1.0004	1.0003	1.0001
5.500	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0040	1.0032	1.0027	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
5.750	1.0088	1.0079	1.0071	1.0064	1.0059	1.0051	1.0044	1.0035	1.0029	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
6.000	1.0096	1.0086	1.0077	1.0070	1.0064	1.0055	1.0048	1.0039	1.0032	1.0026	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0006	1.0004	1.0002
6.250	1.0105	1.0093	1.0084	1.0076	1.0070	1.0060	1.0052	1.0042	1.0035	1.0028	1.0021	1.0017	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
6.500	1.0113	1.0100	1.0090	1.0082	1.0075	1.0064	1.0056	1.0045	1.0038	1.0030	1.0023	1.0018	1.0015	1.0013	1.0011	1.0009	1.0006	1.0005	1.0002
6.750	1.0121	1.0107	1.0097	1.0088	1.0080	1.0069	1.0060	1.0048	1.0040	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
7.000	1.0128	1.0114	1.0103	1.0093	1.0086	1.0073	1.0064	1.0051	1.0043	1.0034	1.0026	1.0021	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
7.250	1.0135	1.0120	1.0108	1.0098	1.0090	1.0077	1.0068	1.0054	1.0045	1.0036	1.0027	1.0022	1.0018	1.0015	1.0014	1.0011	1.0008	1.0005	1.0003
7.500	1.0141	1.0126	1.0113	1.0103	1.0094	1.0081	1.0071	1.0056	1.0047	1.0038	1.0028	1.0023	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003

TABLE 6 — Continued

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REYNOLDS' NUMBER FACTORS — FLANGE TAPS

For 12" Line

Orifice Diam. Inches	$\sqrt{h_w p_f}$																		
	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10	12	15	20	25	30	35	40	50	70	100	200
1.250	1.0180	1.0160	1.0144	1.0131	1.0120	1.0103	1.0090	1.0072	1.0060	1.0048	1.0036	1.0029	1.0024	1.0021	1.0018	1.0014	1.0010	1.0007	1.0004
1.375	1.0169	1.0150	1.0135	1.0123	1.0113	1.0097	1.0085	1.0068	1.0056	1.0045	1.0034	1.0027	1.0023	1.0019	1.0017	1.0014	1.0010	1.0007	1.0003
1.500	1.0159	1.0141	1.0127	1.0116	1.0106	1.0091	1.0079	1.0064	1.0053	1.0042	1.0032	1.0025	1.0021	1.0018	1.0016	1.0013	1.0009	1.0006	1.0003
1.625	1.0149	1.0133	1.0119	1.0109	1.0100	1.0085	1.0075	1.0060	1.0050	1.0040	1.0030	1.0024	1.0020	1.0017	1.0015	1.0012	1.0009	1.0006	1.0003
1.750	1.0140	1.0125	1.0112	1.0102	1.0093	1.0080	1.0070	1.0056	1.0047	1.0037	1.0028	1.0022	1.0019	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003
1.875	1.0132	1.0117	1.0105	1.0096	1.0088	1.0075	1.0066	1.0053	1.0044	1.0035	1.0026	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
2.000	1.0123	1.0110	1.0099	1.0090	1.0082	1.0070	1.0062	1.0049	1.0041	1.0033	1.0025	1.0020	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
2.125	1.0116	1.0103	1.0093	1.0084	1.0077	1.0066	1.0058	1.0046	1.0039	1.0031	1.0023	1.0019	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
2.250	1.0109	1.0096	1.0087	1.0079	1.0072	1.0062	1.0054	1.0043	1.0036	1.0029	1.0022	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
2.375	1.0102	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
2.500	1.0096	1.0085	1.0076	1.0069	1.0064	1.0055	1.0048	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0010	1.0008	1.0005	1.0004	1.0002
2.625	1.0090	1.0080	1.0072	1.0065	1.0060	1.0051	1.0045	1.0036	1.0030	1.0024	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
2.750	1.0084	1.0075	1.0067	1.0061	1.0056	1.0048	1.0042	1.0034	1.0028	1.0022	1.0017	1.0013	1.0011	1.0010	1.0008	1.0007	1.0005	1.0003	1.0002
2.875	1.0079	1.0070	1.0063	1.0058	1.0053	1.0045	1.0040	1.0032	1.0026	1.0021	1.0016	1.0013	1.0011	1.0009	1.0008	1.0006	1.0005	1.0003	1.0002
3.000	1.0075	1.0066	1.0060	1.0054	1.0050	1.0043	1.0037	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0007	1.0006	1.0004	1.0003	1.0001
3.125	1.0070	1.0063	1.0056	1.0051	1.0047	1.0040	1.0035	1.0028	1.0023	1.0019	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
3.250	1.0067	1.0059	1.0053	1.0048	1.0044	1.0038	1.0033	1.0027	1.0022	1.0018	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001
3.375	1.0063	1.0056	1.0051	1.0046	1.0042	1.0036	1.0032	1.0025	1.0021	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
3.500	1.0060	1.0054	1.0048	1.0044	1.0040	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0010	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.625	1.0058	1.0051	1.0046	1.0042	1.0038	1.0033	1.0029	1.0023	1.0019	1.0015	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
3.750	1.0055	1.0049	1.0044	1.0040	1.0037	1.0032	1.0028	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
3.875	1.0053	1.0047	1.0043	1.0039	1.0036	1.0030	1.0027	1.0021	1.0018	1.0014	1.0011	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.000	1.0052	1.0046	1.0041	1.0038	1.0034	1.0030	1.0026	1.0021	1.0017	1.0014	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.250	1.0049	1.0044	1.0040	1.0036	1.0033	1.0028	1.0025	1.0020	1.0016	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.500	1.0048	1.0043	1.0039	1.0035	1.0032	1.0028	1.0024	1.0019	1.0016	1.0013	1.0010	1.0008	1.0006	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
4.750	1.0049	1.0043	1.0039	1.0035	1.0032	1.0028	1.0024	1.0019	1.0016	1.0013	1.0010	1.0008	1.0006	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.000	1.0050	1.0044	1.0040	1.0036	1.0033	1.0028	1.0025	1.0020	1.0017	1.0013	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.250	1.0052	1.0046	1.0042	1.0038	1.0035	1.0030	1.0026	1.0021	1.0017	1.0014	1.0010	1.0008	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001
5.500	1.0055	1.0049	1.0044	1.0040	1.0037	1.0032	1.0028	1.0022	1.0018	1.0015	1.0011	1.0009	1.0007	1.0006	1.0006	1.0004	1.0003	1.0002	1.0001
5.750	1.0059	1.0053	1.0047	1.0043	1.0039	1.0034	1.0030	1.0024	1.0020	1.0016	1.0012	1.0009	1.0008	1.0007	1.0006	1.0005	1.0003	1.0002	1.0001
6.000	1.0064	1.0057	1.0051	1.0046	1.0043	1.0036	1.0032	1.0026	1.0021	1.0017	1.0013	1.0010	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001
6.250	1.0069	1.0061	1.0055	1.0050	1.0046	1.0040	1.0035	1.0028	1.0023	1.0018	1.0014	1.0011	1.0009	1.0008	1.0007	1.0006	1.0004	1.0003	1.0001
6.500	1.0075	1.0067	1.0060	1.0055	1.0050	1.0043	1.0038	1.0030	1.0025	1.0020	1.0015	1.0012	1.0010	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002
6.750	1.0081	1.0072	1.0065	1.0059	1.0054	1.0046	1.0041	1.0033	1.0027	1.0022	1.0016	1.0013	1.0011	1.0009	1.0008	1.0007	1.0005	1.0003	1.0002
7.000	1.0088	1.0078	1.0070	1.0064	1.0059	1.0050	1.0044	1.0035	1.0029	1.0023	1.0018	1.0014	1.0012	1.0010	1.0009	1.0007	1.0005	1.0004	1.0002
7.250	1.0095	1.0084	1.0076	1.0069	1.0063	1.0054	1.0047	1.0038	1.0032	1.0025	1.0019	1.0015	1.0013	1.0011	1.0009	1.0008	1.0005	1.0004	1.0002
7.500	1.0102	1.0090	1.0081	1.0074	1.0068	1.0058	1.0051	1.0041	1.0034	1.0027	1.0020	1.0016	1.0014	1.0012	1.0010	1.0008	1.0006	1.0004	1.0002
7.750	1.0108	1.0096	1.0087	1.0079	1.0072	1.0062	1.0054	1.0043	1.0036	1.0029	1.0022	1.0017	1.0014	1.0012	1.0011	1.0009	1.0006	1.0004	1.0002
8.000	1.0115	1.0102	1.0092	1.0084	1.0077	1.0066	1.0058	1.0046	1.0038	1.0031	1.0023	1.0018	1.0015	1.0013	1.0012	1.0009	1.0007	1.0005	1.0002
8.250	1.0122	1.0108	1.0097	1.0089	1.0081	1.0070	1.0061	1.0049	1.0041	1.0032	1.0024	1.0019	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0002
8.500	1.0128	1.0114	1.0102	1.0093	1.0085	1.0073	1.0064	1.0051	1.0043	1.0034	1.0026	1.0020	1.0017	1.0015	1.0013	1.0010	1.0007	1.0005	1.0003
8.750	1.0133	1.0119	1.0107	1.0097	1.0089	1.0076	1.0067	1.0053	1.0044	1.0036	1.0027	1.0021	1.0018	1.0015	1.0013	1.0011	1.0008	1.0005	1.0003
9.000	1.0138	1.0123	1.0111	1.0101	1.0092	1.0079	1.0069	1.0055	1.0046	1.0037	1.0028	1.0022	1.0018	1.0016	1.0014	1.0011	1.0008	1.0006	1.0003

TABLE 8-A Y_1 EXPANSION FACTORS — FLANGE TAPS

Static Pressure Taken from Upstream Taps

Line Size	ORIFICE SIZES																											
2"	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"					1 3/8"							1 1/2"		
3"	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"				2"			2 1/8"				2 1/4"		
4"	1/8" 1/2"	5/8" 1"	1 1/8" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"			2 5/8"			2 3/4"			2 7/8"			3"	
6"	1/8" 7/8"	1" 1 1/2"	1 3/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"		3 7/8"		4"			4 1/4"				4 1/2"	
8"	1/8" 1 1/8"	1 1/4" 2"	2 1/8" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"			5 1/4"			5 1/2"			5 3/4"			6"	
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 5/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"		6 1/2"			6 3/4"		7"		7 1/4"			7 1/2"	
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2"	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"		7 3/4"		8"		8 1/4"		8 1/2"		8 3/4"		9"	
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"		9 3/4"		10"	10 1/4"		10 1/2"	10 3/4"		11"		11 1/4"	
$\frac{h_w}{p_1}$ Ratio	$\beta = \frac{D_2}{D_1}$ Ratio																											
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9989	.9989	.9989	.9988	.9988	.9988	.9988	.9988	.9988	.9988	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9987	.9986	.9986	.9986	.9986	.9986	.9986	.9986
0.2	.9977	.9977	.9977	.9977	.9976	.9976	.9976	.9976	.9975	.9975	.9975	.9975	.9974	.9974	.9974	.9974	.9974	.9973	.9973	.9973	.9973	.9972	.9972	.9972	.9971	.9971
0.3	.9966	.9966	.9966	.9965	.9965	.9964	.9961	.9963	.9963	.9963	.9962	.9962	.9962	.9961	.9961	.9961	.9960	.9960	.9959	.9959	.9958	.9958	.9958	.9957	.9957	
0.4	.9954	.9954	.9954	.9953	.9953	.9952	.9952	.9951	.9951	.9950	.9949	.9949	.9949	.9948	.9948	.9948	.9947	.9947	.9946	.9946	.9945	.9945	.9944	.9943	.9943	.9942
0.5	.9943	.9943	.9943	.9942	.9941	.9940	.9940	.9939	.9938	.9938	.9937	.9936	.9936	.9935	.9935	.9934	.9934	.9933	.9933	.9932	.9931	.9931	.9930	.9929	.9929	.9928
0.6	.9932	.9932	.9931	.9930	.9929	.9928	.9927	.9927	.9926	.9925	.9924	.9924	.9923	.9923	.9922	.9921	.9921	.9920	.9919	.9918	.9918	.9917	.9916	.9915	.9914	.9913
0.7	.9920	.9920	.9920	.9919	.9918	.9916	.9915	.9915	.9914	.9913	.9912	.9911	.9910	.9910	.9909	.9908	.9907	.9907	.9906	.9905	.9904	.9903	.9902	.9901	.9900	.9899
0.8	.9909	.9909	.9908	.9907	.9906	.9904	.9903	.9902	.9901	.9900	.9899	.9898	.9897	.9897	.9896	.9895	.9894	.9893	.9892	.9891	.9890	.9889	.9888	.9887	.9886	.9884
0.9	.9898	.9897	.9397	.9895	.9894	.9892	.9891	.9890	.9889	.9888	.9986	.9885	.9885	.9884	.9883	.9882	.9381	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9871	.9870
1.0	.9886	.9886	.9885	.9884	.9882	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9872	.9871	.9870	.9869	.9868	.9867	.9865	.9864	.9863	.9861	.9860	.9859	.9857	.9855
1.1	.9875	.9875	.9874	.9872	.9870	.9868	.9867	.9866	.9864	.9863	.9861	.9860	.9859	.9858	.9857	.9856	.9854	.9853	.9852	.9851	.9849	.9848	.9846	.9844	.9843	.9841
1.2	.9863	.9863	.9862	.9860	.9859	.9856	.9855	.9853	.9852	.9850	.9848	.9847	.9846	.9845	.9844	.9843	.9841	.9840	.9838	.9837	.9835	.9834	.9832	.9830	.9828	.9826
1.3	.9852	.9852	.9851	.9849	.9847	.9844	.9843	.9841	.9840	.9838	.9836	.9835	.9833	.9832	.9831	.9829	.9828	.9827	.9825	.9823	.9822	.9820	.9818	.9816	.9814	.9812
1.4	.9841	.9840	.9840	.9837	.9835	.9832	.9831	.9829	.9827	.9825	.9823	.9822	.9821	.9819	.9818	.9816	.9815	.9813	.9812	.9810	.9808	.9806	.9804	.9802	.9800	.9798
1.5	.9829	.9829	.9828	.9826	.9823	.9820	.9819	.9817	.9815	.9813	.9810	.9809	.9808	.9306	.9805	.9803	.9802	.9800	.9798	.9796	.9794	.9792	.9790	.9788	.9786	.9783
1.6	.9818	.9818	.9817	.9814	.9811	.9808	.9306	.9805	.9803	.9800	.9798	.9796	.9795	.9793	.9792	.9790	.9788	.9787	.9785	.9783	.9781	.9778	.9776	.9774	.9771	.9769
1.7	.9806	.9806	.9805	.9802	.9800	.9796	.9794	.9792	.9790	.9788	.9785	.9784	.9782	.9780	.9779	.9777	.9775	.9773	.9771	.9769	.9767	.9764	.9762	.9760	.9757	.9754
1.8	.9795	.9795	.9794	.9791	.9788	.9784	.9782	.9780	.9778	.9775	.9772	.9771	.9769	.9768	.9766	.9764	.9762	.9760	.9758	.9755	.9753	.9751	.9748	.9745	.9743	.9740
1.9	.9784	.9783	.9782	.9779	.9776	.9772	.9770	.9768	.9766	.9763	.9760	.9758	.9756	.9755	.9753	.9751	.9749	.9747	.9744	.9742	.9739	.9737	.9734	.9731	.9728	.9725
2.0	.9772	.9772	.9771	.9767	.9764	.9760	.9758	.9756	.9753	.9750	.9747	.9745	.9744	.9742	.9740	.9738	.9735	.9733	.9731	.9728	.9726	.9723	.9720	.9717	.9714	.9711
2.1	.9761	.9761	.9759	.9756	.9753	.9748	.9746	.9744	.9741	.9738	.9734	.9733	.9731	.9729	.9727	.9725	.9722	.9720	.9717	.9715	.9712	.9709	.9706	.9703	.9700	.9696
2.2	.9750	.9749	.9748	.9744	.9741	.9736	.9734	.9731	.9729	.9725	.9722	.9720	.9718	.9716	.9714	.9711	.9709	.9706	.9704	.9701	.9698	.9695	.9692	.9689	.9685	.9682
2.3	.9738	.9738	.9736	.9732	.9729	.9724	.9722	.9719	.9716	.9713	.9709	.9707	.9705	.9703	.9701	.9698	.9696	.9693	.9690	.9688	.9685	.9681	.9678	.9675	.9671	.9667
2.4	.9727	.9726	.9725	.9721	.9717	.9712	.9710	.9707	.9704	.9700	.9697	.9694	.9692	.9690	.9688	.9685	.9683	.9680	.9677	.9674	.9671	.9668	.9664	.9661	.9657	.9653
2.5	.9715	.9715	.9713	.9709	.9705	.9700	.9698	.9695	.9692	.9688	.9684	.9682	.9680	.9677	.9675	.9672	.9669	.9666	.9663	.9660	.9657	.9654	.9650	.9646	.9643	.9639
2.6	.9704	.9704	.9702	.9698	.9694	.9688	.9686	.9683	.9679	.9675	.9671	.9669	.9667	.9664	.9662	.9659	.9656	.9653	.9650	.9647	.9643	.9640	.9636	.9632	.9628	.9624
2.7	.9693	.9692	.9691	.9686	.9682	.9676	.9673	.9670	.9667	.9663	.9659	.9656	.9654	.9651	.9649	.9646	.9643	.9640	.9637	.9633	.9630	.9626	.9622	.9618	.9614	.9610
2.8	.9681	.9681	.9679	.9674	.9670	.9664	.9661	.9658	.9654	.9650	.9646	.9644	.9641	.9638	.9636	.9633	.9630	.9626	.9623	.9620	.9616	.9612	.9608	.9604	.9600	.9595
2.9	.9670	.9669	.9668	.9663	.9658	.9652	.9649	.9646	.9642	.9638	.9633	.9631	.9628	.9625	.9623	.9620	.9616	.9613	.9610	.9606	.9602	.9598	.9594	.9590	.9585	.9581
3.0	.9658	.9658	.9656	.9651	.9647	.9640	.9637	.9634	.9630	.9626	.9621	.9618	.9615	.9613	.9610	.9606	.9603	.9600	.9596	.9592	.9588	.9584	.9580	.9576	.9571	.9566
3.1	.9647	.9647	.9645	.9639	.9635	.9628	.9625	.9622	.9617	.9613	.9608	.9605	.9603	.9600	.9597	.9593	.9590	.9586	.9583	.9579	.9575	.9571	.9566	.9562	.9557	.9552
3.2	.9636	.9635	.9633	.9628	.9623	.9616	.9613	.9609	.9605	.9601	.9595	.9593	.9590	.9587	.9584	.9580	.9577	.9573	.9569	.9565	.9561	.9557	.9552	.9547	.9542	.9537
3.3	.9624	.9624	.9622	.9616	.9611	.9604	.9601	.9597	.9593	.9588	.9583	.9580	.9577	.9574	.9571	.9567	.9564	.9560	.9556	.9552	.9547	.9543	.9538	.9533	.9528	.9523
3.4	.9613	.9612	.9610	.9604	.9599	.9592	.9589	.9585	.9580	.9576	.9570	.9567	.9564	.9561	.9558	.9554	.9550	.9546	.9542	.9538	.9534	.9529	.9524	.9519	.9514	.9508
3.5	.9602	.9601	.9599	.9593	.9588	.9580	.9577	.9573	.9568	.9563	.9558	.9554	.9551	.9548	.9545	.9541	.9537	.9533	.9529	.9524	.9520	.9515	.9510	.9505	.9500	.9494
3.6	.9590	.9590	.9587	.9581	.9576	.9568	.9565	.9560	.9556	.9551	.9545	.9542	.9538	.9535	.9532	.9528	.9524	.9520	.9515	.9511	.9506	.9501	.9496	.9491	.9485	.9480
3.7	.9579	.9578	.9576	.9570	.9564	.9556	.9553	.9548	.9543	.9538	.9532	.9529	.9526	.9522	.9518	.9515	.9511	.9506	.9502	.9497	.9492	.9487	.9482	.9477	.9471	.9465
3.8	.9567	.9567	.9564	.9558	.9552	.9544	.9540	.9536	.9531	.9526	.9520	.9516	.9513	.9509	.9505	.9502	.9497	.9493	.9488	.9484	.9479	.9474	.9468	.9463	.9457	.9451
3.9	.9556	.9555	.9553	.9546	.9540	.9532	.9528	.9524	.9519	.9513	.9507	.9504	.9500	.9496	.9492	.9488	.9484	.9480	.9475	.9470	.9465	.9460	.9454	.9448	.9442	.9436
4.0	.9545	.9544	.9542	.9535	.9529	.9520	.9516	.9512	.9506	.9501	.9494	.9491	.9487	.9483	.9479	.9475	.9471	.9465	.9462	.9457	.9451	.9446	.9440	.9434	.9428	.9422

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

TABLE 9-A Y_2 EXPANSION FACTORS — FLANGE TAPS

Static Pressure Taken from Downstream Taps

Line Size	ORIFICE SIZES																										
2"	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"					1 3/8"							1 1/2"		
3"	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"				2"				2 1/8"				2 1/4"		
4"	1/8" 1/2"	5/8" 1"	1 1/8" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"			2 5/8"			2 3/4"			2 7/8"			3"	
6"	1/8" 7/8"	1" 1 1/2"	1 5/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"		3 7/8"		4"				4 1/4"				4 1/2"	
8"	1/8" 1 1/8"	1 1/4" 2"	2 1/8" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"			5 1/4"			5 1/2"			5 3/4"			6"	
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 3/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"		6 1/2"			6 3/4"		7"		7 1/4"			7 1/2"	
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2"	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"		7 3/4"		8"		8 1/4"		8 1/2"		8 3/4"		9"	
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"		9 3/4"		10"	10 1/4"		10 1/2"	10 3/4"		11"		11 1/4"	

h_w/P_2 Ratio	$\beta = D_2/D_1$, Ratio																										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.1	1.0007	1.0007	1.0007	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004
0.2	1.0013	1.0013	1.0013	1.0013	1.0013	1.0012	1.0012	1.0012	1.0012	1.0011	1.0011	1.0011	1.0011	1.0010	1.0010	1.0010	1.0010	1.0010	1.0009	1.0009	1.0009	1.0008	1.0008	1.0008	1.0008	1.0007
0.3	1.0020	1.0020	1.0020	1.0020	1.0019	1.0018	1.0018	1.0018	1.0017	1.0017	1.0016	1.0016	1.0016	1.0016	1.0015	1.0015	1.0115	1.0014	1.0014	1.0014	1.0013	1.0013	1.0012	1.0012	1.0011	1.0011
0.4	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0024	1.0024	1.0023	1.0023	1.0022	1.0022	1.0021	1.0021	1.0021	1.0020	1.0020	1.0019	1.0019	1.0018	1.0018	1.0017	1.0017	1.0016	1.0015	1.0015
0.5	1.0033	1.0033	1.0033	1.0032	1.0031	1.0030	1.0029	1.0029	1.0028	1.0028	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0025	1.0024	1.0024	1.0023	1.0022	1.0022	1.0021	1.0020	1.0019	1.0019
0.6	1.0040	1.0040	1.0040	1.0039	1.0038	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0032	1.0031	1.0031	1.0030	1.0030	1.0029	1.0028	1.0027	1.0027	1.0026	1.0025	1.0024	1.0023	1.0022	1.0022
0.7	1.0047	1.0047	1.0047	1.0045	1.0044	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0033	1.0037	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0031	1.0030	1.0029	1.0028	1.0026	1.0025
0.8	1.0053	1.0053	1.0053	1.0051	1.0050	1.0049	1.0048	1.0047	1.0046	1.0045	1.0044	1.0043	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0037	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0029
0.9	1.0060	1.0060	1.0060	1.0058	1.0057	1.0055	1.0054	1.0053	1.0052	1.0050	1.0049	1.0048	1.0048	1.0047	1.0046	1.0045	1.0043	1.0042	1.0041	1.0040	1.0039	1.0039	1.0037	1.0036	1.0035	1.0033
1.0	1.0067	1.0066	1.0066	1.0064	1.0063	1.0061	1.0060	1.0059	1.0058	1.0056	1.0055	1.0054	1.0053	1.0052	1.0051	1.0050	1.0049	1.0048	1.0046	1.0045	1.0044	1.0043	1.0041	1.0040	1.0039	1.0037
1.1	1.0074	1.0073	1.0073	1.0071	1.0069	1.0067	1.0066	1.0065	1.0063	1.0061	1.0060	1.0059	1.0058	1.0057	1.0056	1.0055	1.0054	1.0053	1.0051	1.0050	1.0049	1.0047	1.0046	1.0044	1.0042	1.0040
1.2	1.0080	1.0080	1.0079	1.0077	1.0075	1.0073	1.0072	1.0071	1.0069	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0060	1.0059	1.0057	1.0056	1.0054	1.0053	1.0051	1.0050	1.0048	1.0046	1.0044
1.3	1.0087	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0077	1.0075	1.0073	1.0071	1.0070	1.0069	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0059	1.0058	1.0056	1.0054	1.0052	1.0050	1.0048
1.4	1.0094	1.0093	1.0093	1.0090	1.0088	1.0086	1.0084	1.0083	1.0081	1.0079	1.0077	1.0076	1.0074	1.0073	1.0072	1.0070	1.0069	1.0067	1.0065	1.0063	1.0062	1.0060	1.0058	1.0056	1.0054	1.0052
1.5	1.0100	1.0100	1.0099	1.0097	1.0094	1.0091	1.0090	1.0088	1.0086	1.0084	1.0082	1.0081	1.0080	1.0078	1.0077	1.0075	1.0074	1.0072	1.0070	1.0068	1.0067	1.0065	1.0063	1.0060	1.0058	1.0056
1.6	1.0108	1.0107	1.0106	1.0104	1.0101	1.0097	1.0097	1.0095	1.0093	1.0090	1.0088	1.0086	1.0085	1.0083	1.0081	1.0080	1.0078	1.0076	1.0075	1.0073	1.0071	1.0069	1.0066	1.0064	1.0062	1.0059
1.7	1.0114	1.0114	1.0113	1.0110	1.0108	1.0104	1.0103	1.0101	1.0099	1.0096	1.0094	1.0092	1.0091	1.0089	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0076	1.0074	1.0071	1.0069	1.0066	1.0064
1.8	1.0121	1.0120	1.0120	1.0117	1.0114	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0097	1.0096	1.0094	1.0092	1.0091	1.0089	1.0087	1.0084	1.0082	1.0080	1.0078	1.0075	1.0073	1.0070	1.0067
1.9	1.0128	1.0127	1.0126	1.0123	1.0120	1.0116	1.0115	1.0112	1.0110	1.0107	1.0104	1.0103	1.0101	1.0099	1.0097	1.0095	1.0093	1.0091	1.0089	1.0087	1.0084	1.0082	1.0079	1.0077	1.0074	1.0071
2.0	1.0134	1.0133	1.0132	1.0129	1.0126	1.0122	1.0121	1.0118	1.0116	1.0113	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0098	1.0096	1.0094	1.0092	1.0089	1.0087	1.0084	1.0081	1.0078	1.0075
2.1	1.0140	1.0140	1.0139	1.0136	1.0133	1.0129	1.0127	1.0124	1.0122	1.0119	1.0115	1.0114	1.0111	1.0110	1.0108	1.0105	1.0103	1.0101	1.0099	1.0096	1.0094	1.0091	1.0088	1.0085	1.0082	1.0079
2.2	1.0147	1.0147	1.0146	1.0142	1.0139	1.0135	1.0133	1.0130	1.0128	1.0125	1.0121	1.0120	1.0118	1.0116	1.0114	1.0111	1.0109	1.0107	1.0104	1.0101	1.0098	1.0095	1.0094	1.0089	1.0086	1.0083
2.3	1.0154	1.0154	1.0153	1.0149	1.0146	1.0141	1.0139	1.0136	1.0133	1.0130	1.0127	1.0125	1.0123	1.0121	1.0119	1.0116	1.0114	1.0111	1.0109	1.0106	1.0103	1.0100	1.0097	1.0093	1.0090	1.0086
2.4	1.0160	1.0160	1.0159	1.0154	1.0151	1.0146	1.0144	1.0141	1.0138	1.0135	1.0133	1.0130	1.0128	1.0126	1.0124	1.0121	1.0119	1.0116	1.0114	1.0111	1.0108	1.0105	1.0102	1.0098	1.0095	1.0091
2.5	1.0167	1.0167	1.0166	1.0162	1.0158	1.0153	1.0150	1.0148	1.0145	1.0141	1.0137	1.0135	1.0133	1.0131	1.0128	1.0126	1.0123	1.0120	1.0118	1.0115	1.0112	1.0109	1.0106	1.0102	1.0098	1.0094
2.6	1.0174	1.0173	1.0172	1.0168	1.0164	1.0159	1.0156	1.0154	1.0151	1.0147	1.0143	1.0141	1.0139	1.0136	1.0134	1.0131	1.0128	1.0125	1.0123	1.0120	1.0116	1.0113	1.0110	1.0106	1.0102	1.0099
2.7	1.0183	1.0182	1.0181	1.0176	1.0172	1.0167	1.0164	1.0161	1.0158	1.0154	1.0150	1.0148	1.0146	1.0143	1.0141	1.0138	1.0135	1.0132	1.0129	1.0126	1.0123	1.0119	1.0115	1.0111	1.0107	1.0103
2.8	1.0187	1.0186	1.0185	1.0180	1.0176	1.0171	1.0168	1.0165	1.0162	1.0158	1.0154	1.0152	1.0149	1.0147	1.0144	1.0141	1.0139	1.0136	1.0132	1.0129	1.0126	1.0122	1.0118	1.0114	1.0110	1.0106
2.9	1.0194	1.0194	1.0192	1.0187	1.0183	1.0177	1.0175	1.0172	1.0168	1.0164	1.0160	1.0157	1.0155	1.0152	1.0150	1.0147	1.0144	1.0141	1.0137	1.0134	1.0130	1.0127	1.0123	1.0119	1.0114	1.0110
3.0	1.0200	1.0200	1.0198	1.0193	1.0189	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0162	1.0160	1.0157	1.0155	1.0152	1.0149	1.0146	1.0142	1.0139	1.0135	1.0131	1.0127	1.0123	1.0119	1.0114
3.1	1.0207	1.0206	1.0205	1.0200	1.0195	1.0189	1.0186	1.0183	1.0179	1.0175	1.0171	1.0168	1.0166	1.0163	1.0160	1.0157	1.0153	1.0150	1.0147	1.0143	1.0139	1.0135	1.0131	1.0127	1.0123	1.0118
3.2	1.0213	1.0213	1.0211	1.0206	1.0201	1.0195	1.0192	1.0189	1.0185	1.0180	1.0176	1.0173	1.0171	1.0168	1.0165	1.0162	1.0158	1.0155	1.0152	1.0148	1.0144	1.0140	1.0136	1.0131	1.0127	1.0122
3.3	1.0220	1.0220	1.0218	1.0213	1.0208	1.0202	1.0199	1.0195	1.0191	1.0186	1.0181	1.0178	1.0176	1.0173	1.0170	1.0166	1.0163	1.0159	1.0156	1.0152	1.0148	1.0144	1.0139	1.0135	1.0130	1.0125
3.4	1.0227	1.0227	1.0225	1.0219	1.0214	1.0208	1.0205	1.0201	1.0197	1.0192	1.0187	1.0184	1.0182	1.0179	1.0175	1.0172	1.0169	1.0165	1.0161	1.0157	1.0153	1.0149	1.0144	1.0139	1.0135	1.0129
3.5	1.0233	1.0233	1.0231	1.0225	1.0220	1.0214	1.0210	1.0207	1.0202	1.0198	1.0192	1.0190	1.0187	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0161	1.0157	1.0153	1.0148	1.0143	1.0139	1.0133
3.6	1.0240	1.0239	1.0237	1.0232	1.0227	1.0220	1.0216	1.0212	1.0208	1.0203	1.0198	1.0195	1.0192	1.0188	1.0185	1.0182	1.0178	1.0174	1.0170	1.0166	1.0162	1.0158	1.0153	1.0148	1.0143	1.0138
3.7	1.0246	1.0246	1.0244	1.0238	1.0232	1.0225	1.0221	1.0217	1.0213	1.0208	1.0203	1.0200	1.0197	1.0193	1.0190	1.0187	1.0183	1.0179	1.0175	1.0171	1.0166	1.0162	1.0157	1.0152	1.0146	1.0141
3.8	1.0252	1.0252	1.0250	1.0244	1.0238	1.0231	1.0227	1.0223	1.0219	1.0214	1.0209	1.0206	1.0203	1.0199	1.0196	1.0192	1.0189	1.0185	1.0180	1.0176	1.0171	1.0167	1.0162	1.0156	1.0151	1.0145
3.9	1.0259	1.0259	1.0257	1.0250	1.0245	1.0237	1.0234	1.0229	1.0225	1.0220	1.0214	1.0211	1.0208	1.0205	1.0201	1.0197	1.0193	1.0189	1.0185	1.0180	1.0176	1.0171	1.0166	1.0160	1.0155	1.0149
4.0	1.0265	1.0265	1.0263	1.0256	1.0251	1.0243	1.0240	1.0235	1.0231	1.0225	1.0220	1.0217	1.0213	1.0210	1.0206	1.0202	1.0198	1.0194	1.0190	1.0185	1.0180	1.0175	1.0170	1.0164	1.0159	1.0153

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

TABLE 10-A Y_m EXPANSION FACTORS — FLANGE TAPS

Static Pressure, Mean of Upstream and Downstream

Line Size	ORIFICE SIZES																										
2"	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"					1 3/8"							1 1/2"		
3"	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"				2"				2 1/8"				2 1/4"		
4"	1/8" 1/2"	5/8" 1"	1 1/8" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"			2 5/8"			2 3/4"			2 7/8"			3"	
6"	1/8" 7/8"	1" 1 1/2"	1 5/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"		3 7/8"		4"				4 1/4"				4 1/2"	
8"	1/8" 1 1/8"	1 1/4" 2"	2 1/8" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"			5 1/4"			5 1/2"			5 3/4"			6"	
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 5/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"		6 1/2"			6 3/4"		7"		7 1/4"			7 1/2"	
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2"	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"		7 3/4"		8"		8 1/4"		8 1/2"		8 3/4"		9"	
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"		9 3/4"		10"	10 1/4"		10 1/2"	10 3/4"		11"		11 1/4"	
$\frac{h_w}{P_m}$ Ratio	$\beta = \frac{D_2}{D_1}$, Ratio																										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.1	.9998	.9998	.9998	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9995	.9995	.9995	.9995	.9995	.9995	.9995
0.2	.9995	.9995	.9995	.9995	.9994	.9994	.9994	.9994	.9993	.9993	.9993	.9993	.9992	.9992	.9992	.9992	.9992	.9991	.9991	.9991	.9991	.9990	.9990	.9990	.9989	.9989
0.3	.9993	.9993	.9993	.9992	.9992	.9991	.9991	.9990	.9990	.9990	.9989	.9989	.9989	.9988	.9988	.9988	.9987	.9987	.9987	.9986	.9986	.9986	.9985	.9985	.9984	.9984
0.4	.9991	.9991	.9990	.9990	.9989	.9988	.9988	.9987	.9987	.9986	.9986	.9985	.9985	.9984	.9984	.9984	.9983	.9983	.9982	.9982	.9981	.9981	.9980	.9980	.9979	.9978
0.5	.9988	.9988	.9988	.9987	.9986	.9985	.9985	.9984	.9983	.9983	.9982	.9981	.9981	.9981	.9980	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9975	.9974	.9974	.9973
0.6	.9986	.9986	.9985	.9984	.9984	.9982	.9982	.9981	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9975	.9975	.9974	.9973	.9973	.9972	.9971	.9970	.9969	.9968	.9967
0.7	.9984	.9984	.9983	.9982	.9981	.9979	.9979	.9978	.9977	.9976	.9975	.9974	.9973	.9973	.9972	.9971	.9971	.9970	.9969	.9968	.9967	.9966	.9965	.9964	.9963	.9962
0.8	.9981	.9981	.9981	.9979	.9978	.9976	.9976	.9975	.9974	.9972	.9971	.9970	.9970	.9969	.9968	.9967	.9967	.9965	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957
0.9	.9979	.9979	.9978	.9977	.9975	.9973	.9973	.9972	.9971	.9969	.9968	.9967	.9967	.9966	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957	.9956	.9955	.9953	.9952
1.0	.9977	.9977	.9976	.9975	.9973	.9971	.9970	.9969	.9968	.9967	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9958	.9957	.9955	.9954	.9953	.9951	.9950	.9948	.9947
1.1	.9975	.9974	.9974	.9972	.9971	.9968	.9967	.9966	.9965	.9963	.9961	.9960	.9959	.9958	.9957	.9956	.9955	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941
1.2	.9973	.9973	.9972	.9970	.9968	.9966	.9964	.9963	.9961	.9960	.9958	.9957	.9955	.9954	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941	.9940	.9938	.9936
1.3	.9971	.9970	.9970	.9967	.9965	.9963	.9961	.9960	.9958	.9956	.9954	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9942	.9940	.9938	.9936	.9934	.9933	.9931
1.4	.9968	.9968	.9967	.9965	.9963	.9960	.9958	.9957	.9955	.9953	.9951	.9949	.9948	.9947	.9945	.9944	.9942	.9941	.9939	.9938	.9936	.9934	.9932	.9930	.9928	.9926
1.5	.9966	.9966	.9965	.9962	.9960	.9957	.9955	.9954	.9952	.9950	.9948	.9946	.9945	.9944	.9942	.9941	.9939	.9937	.9935	.9933	.9932	.9929	.9927	.9925	.9923	.9920
1.6	.9964	.9964	.9962	.9960	.9957	.9954	.9952	.9950	.9948	.9946	.9944	.9943	.9941	.9940	.9938	.9937	.9935	.9933	.9931	.9929	.9927	.9925	.9922	.9920	.9918	.9915
1.7	.9962	.9962	.9960	.9958	.9955	.9952	.9950	.9948	.9946	.9943	.9941	.9939	.9938	.9936	.9934	.9933	.9931	.9929	.9927	.9925	.9923	.9921	.9918	.9916	.9913	.9910
1.8	.9959	.9959	.9958	.9955	.9953	.9949	.9947	.9945	.9943	.9940	.9937	.9936	.9934	.9932	.9930	.9928	.9927	.9925	.9923	.9920	.9918	.9916	.9913	.9911	.9908	.9905
1.9	.9957	.9957	.9956	.9953	.9950	.9948	.9944	.9942	.9940	.9937	.9934	.9933	.9931	.9929	.9927	.9925	.9923	.9921	.9919	.9916	.9914	.9911	.9908	.9906	.9903	.9900
2.0	.9955	.9954	.9953	.9950	.9946	.9942	.9940	.9938	.9935	.9932	.9929	.9927	.9925	.9923	.9921	.9919	.9917	.9915	.9912	.9910	.9907	.9904	.9901	.9899	.9896	.9892
2.1	.9953	.9953	.9952	.9948	.9945	.9940	.9938	.9936	.9933	.9930	.9927	.9925	.9923	.9921	.9919	.9917	.9915	.9913	.9910	.9908	.9905	.9902	.9899	.9896	.9893	.9890
2.2	.9951	.9951	.9950	.0047	.9943	.9938	.9936	.9934	.9931	.9927	.9924	.9922	.9920	.9918	.9916	.9913	.9911	.9908	.9906	.9903	.9900	.9897	.9894	.9892	.9888	.9884
2.3	.9949	.9949	.9947	.9944	.9940	.9936	.9933	.9931	.9928	.9924	.9921	.9919	.9917	.9915	.9913	.9910	.9908	.9905	.9902	.9900	.9897	.9894	.9891	.9887	.9884	.9980
2.4	.9947	.9947	.9945	.9941	.9938	.9933	.9930	.9927	.9924	.9921	.9917	.9915	.9913	.9911	.9909	.9906	.9904	.9901	.9898	.9895	.9892	.9889	.9886	.9882	.9878	.9875
2.5	.9945	.9944	.9943	.9938	.9935	.9930	.9927	.9924	.9921	.9918	.9914	.9912	.9909	.9907	.9905	.9902	.9900	.9897	.9894	.9891	.9888	.9885	.9881	.9878	.9874	.9870
2.6	.9943	.9942	.9941	.9936	.9933	.9928	.9925	.9922	.9919	.9915	.9911	.9909	.9907	.9904	.9902	.9899	.9896	.9893	.9890	.9887	.9884	.9880	.9876	.9873	.9869	.9865
2.7	.9941	.9941	.9939	.9934	.9930	.9925	.9922	.9919	.9916	.9912	.9907	.9905	.9903	.9900	.9898	.9895	.9892	.9889	.9886	.9883	.9880	.9876	.9872	.9869	.9864	.9860
2.8	.9939	.9938	.9937	.9932	.9928	.9922	.9919	.9916	.9913	.9909	.9904	.9902	.9900	.9897	.9895	.9892	.9889	.9886	.9882	.9879	.9875	.9871	.9867	.9864	.9859	.9855
2.9	.9937	.9936	.9934	.9929	.9925	.9919	.9916	.9913	.9909	.9905	.9901	.9899	.9896	.9893	.9891	.9888	.9885	.9882	.9878	.9874	.9871	.9867	.9863	.9859	.9855	.9850
3.0	.9935	.9934	.9932	.9927	.9923	.9917	.9914	.9911	.9907	.9903	.9898	.9895	.9892	.9890	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845
3.1	.9932	.9932	.9930	.9925	.9920	.9914	.9911	.9908	.9904	.9900	.9895	.9892	.9890	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845	.9840
3.2	.9931	.9931	.9929	.9923	.9919	.9912	.9909	.9905	.9901	.9897	.9892	.9889	.9886	.9883	.9880	.9877	.9873	.9870	.9866	.9862	.9858	.9854	.9850	.9845	.9840	.9835
3.3	.9929	.9928	.9926	.9921	.9916	.9909	.9906	.9902	.9898	.9894	.9889	.9886	.9883	.9880	.9877	.9873	.9870	.9866	.9863	.9859	.9854	.9850	.9845	.9841	.9836	.9831
3.4	.9927	.9926	.9924	.9918	.9913	.9907	.9903	.9899	.9895	.9890	.9885	.9882	.9789	.9876	.9873	.9859	.9866	.9862	.9858	.9854	.9850	.9845	.9841	.9836	.9831	.9825
3.5	.9925	.9924	.9922	.9916	.9911	.9905	.9901	.9897	.9893	.9888	.9883	.9880	.9877	.9873	.9870	.9866	.9863	.9859	.9855	.9850	.9846	.9841	.9837	.9832	.9826	.9821
3.6	.9923	.9923	.9920	.9914	.9909	.9902	.9898	.9894	.9890	.9885	.9878	.9876	.9873	.9869	.9866	.9862	.9859	.9855	.9851	.9846	.9842	.9837	.9833	.9827	.9822	.9816
3.7	.9921	.9920	.9918	.9912	.9907	.9899	.9895	.9891	.9887	.9882	.9876	.9873	.9870	.9866	.9863	.9859	.9855	.9851	.9847	.9842	.9838	.9833	.9828	.9822	.9817	.9811
3.8	.9919	.9918	.9916	.9910	.9905	.9897	.9893	.9889	.9884	.9879	.9873	.9870	.9866	.9863	.9859	.9855	.9851	.9847	.9843	.9838	.9834	.9829	.9824	.9818	.9813	.9807
3.9	.9918	.9917	.9915	.9908	.9902	.9894	.9890	.9886	.9881	.9876	.9870	.9867	.9863	.9860	.9856	.9852	.9848	.9844	.9839	.9835	.9830	.9825	.9820	.9814	.9808	.9802
4.0	.9916	.9915	.9913	.9906	.9900	.9892	.9888	.9884	.9879	.9873	.9867	.9864	.9861	.9857	.9853	.9849	.9845	.9840	.9836	.9831	.9826	.9820	.9815	.9809	.9803	.9797

NOTE: Above tables are for use on natural gas and are based on ratio of specific heats equal to 1.30.

FACTORS TO CHANGE FROM A TEMPERATURE BASE OF 60° F. to CONTRACT TEMPERATURE BASE

Temperature Degrees F.	F_{tb}	Temperature Degrees F.	F_{tb}
40	.9615	65	1.0096
41	.9635	66	1.0115
42	.9654	67	1.0135
43	.9673	68	1.0154
44	.9692	69	1.0173
45	.9712	70	1.0192
46	.9731	71	1.0212
47	.9750	72	1.0231
48	.9769	73	1.0250
49	.9788	74	1.0269
50	.9808	75	1.0288
51	.9827	76	1.0308
52	.9846	77	1.0327
53	.9865	78	1.0346
54	.9885	79	1.0365
55	.9904	80	1.0385
56	.9923	81	1.0404
57	.9942	82	1.0423
58	.9962	83	1.0442
59	.9981	84	1.0462
60	1.0000	85	1.0481
61	1.0019	86	1.0500
62	1.0038	87	1.0519
63	1.0058	88	1.0538
64	1.0077	89	1.0558
		90	1.0577

TABLE 14
F_{tb}

FACTORS TO CHANGE FROM A PRESSURE BASE OF 14.4 LB. PER SQ. IN. ABSOLUTE TO SOME OTHER CONTRACT PRESSURE BASE

CONTRACT PRESSURE BASE			F_{pb} Correction Factors
Above 14.4		Absolute Lb.	
Oz.	Lb.		
2	.125	14.525	.9914
4	.250	14.65	.9829
(30" Hg., Absolute)		14.73	.9776
6	.375	14.775	.9746
8	.500	14.90	.9664
10	.625	15.025	.9584
12	.750	15.15	.9505
14	.875	15.275	.9427
16	1.000	15.40	.9351
18	1.125	15.525	.9275
20	1.250	15.65	.9201
22	1.375	15.775	.9128
24	1.500	15.90	.9057
26	1.625	16.025	.8986
28	1.750	16.15	.8916
30	1.875	16.275	.8848
32	2.000	16.40	.8780
34	2.125	16.525	.8714
36	2.250	16.65	.8649
38	2.375	16.775	.8584
40	2.500	16.90	.8521
42	2.625	17.025	.8458
44	2.750	17.15	.8397
46	2.875	17.275	.8336
48	3.000	17.40	.8276

TABLE 13
F_{pb}

FACTOR TO CHANGE FROM FLOWING TEMPERATURE OF 60° FAHRENHEIT TO ACTUAL FLOWING TEMPERATURE

Temp. °F.	F_{tf}	Temp. °F.	F_{tf}	Temp. °F.	F_{tf}
1	1.0621	51	1.0088	101	.9628
2	1.0609	52	1.0078	102	.9619
3	1.0598	53	1.0068	103	.9610
4	1.0586	54	1.0058	104	.9602
5	1.0575	55	1.0048	105	.9594
6	1.0564	56	1.0039	106	.9585
7	1.0552	57	1.0029	107	.9577
8	1.0541	58	1.0019	108	.9568
9	1.0530	59	1.0010	109	.9560
10	1.0518	60	1.0000	110	.9551
11	1.0507	61	.9990	111	.9543
12	1.0496	62	.9981	112	.9535
13	1.0485	63	.9971	113	.9526
14	1.0474	64	.9962	114	.9518
15	1.0463	65	.9952	115	.9510
16	1.0452	66	.9943	116	.9501
17	1.0441	67	.9933	117	.9493
18	1.0430	68	.9924	118	.9485
19	1.0419	69	.9915	119	.9477
20	1.0408	70	.9905	120	.9469
21	1.0398	71	.9896	121	.9460
22	1.0387	72	.9887	122	.9452
23	1.0376	73	.9877	123	.9444
24	1.0365	74	.9868	124	.9436
25	1.0355	75	.9859	125	.9428
26	1.0344	76	.9850	126	.9420
27	1.0333	77	.9840	127	.9412
28	1.0323	78	.9831	128	.9404
29	1.0312	79	.9822	129	.9396
30	1.0302	80	.9813	130	.9388
31	1.0291	81	.9804	131	.9380
32	1.0281	82	.9795	132	.9372
33	1.0270	83	.9786	133	.9364
34	1.0260	84	.9777	134	.9356
35	1.0249	85	.9768	135	.9349
36	1.0239	86	.9759	136	.9341
37	1.0229	87	.9750	137	.9333
38	1.0218	88	.9741	138	.9325
39	1.0208	89	.9732	139	.9317
40	1.0198	90	.9723	140	.9309
41	1.0188	91	.9715	141	.9302
42	1.0178	92	.9706	142	.9294
43	1.0168	93	.9697	143	.9286
44	1.0158	94	.9688	144	.9279
45	1.0147	95	.9680	145	.9271
46	1.0137	96	.9671	146	.9263
47	1.0127	97	.9662	147	.9256
48	1.0117	98	.9653	148	.9248
49	1.0108	99	.9645	149	.9240
50	1.0098	100	.9636	150	.9233

TABLE 15
F_{tf}

FACTORS TO ADJUST FOR SPECIFIC GRAVITY

Flowing Gravity G	F_g	Flowing Gravity G	F_g	Flowing Gravity G	F_g
.500	1.4142	.675	1.2172	.850	1.0847
.505	1.4072	.680	1.2127	.855	1.0815
.510	1.4003	.685	1.2082	.860	1.0783
.515	1.3935	.690	1.2039	.865	1.0752
.520	1.3868	.695	1.1995	.870	1.0721
.525	1.3801	.700	1.1952	.875	1.0690
.530	1.3736	.705	1.1910	.880	1.0660
.535	1.3672	.710	1.1868	.885	1.0630
.540	1.3608	.715	1.1826	.890	1.0600
.545	1.3546	.720	1.1785	.895	1.0570
.550	1.3484	.725	1.1744	.900	1.0541
.555	1.3423	.730	1.1704	.905	1.0512
.560	1.3363	.735	1.1664	.910	1.0483
.565	1.3304	.740	1.1625	.915	1.0454
.570	1.3245	.745	1.1586	.920	1.0426
.575	1.3188	.750	1.1547	.925	1.0398
.580	1.3131	.755	1.1509	.930	1.0370
.585	1.3074	.760	1.1471	.935	1.0342
.590	1.3019	.765	1.1433	.940	1.0314
.595	1.2964	.770	1.1396	.945	1.0287
.600	1.2910	.775	1.1359	.950	1.0260
.605	1.2856	.780	1.1323	.955	1.0233
.610	1.2804	.785	1.1287	.960	1.0206
.615	1.2752	.790	1.1251	.965	1.0180
.620	1.2700	.795	1.1215	.970	1.0153
.625	1.2649	.800	1.1180	.975	1.0127
.630	1.2599	.805	1.1146	.980	1.0102
.635	1.2549	.810	1.1111	.985	1.0076
.640	1.2500	.815	1.1077	.990	1.0050
.645	1.2451	.820	1.1043	.995	1.0025
.650	1.2403	.825	1.1010	1.000	1.0000
.655	1.2356	.830	1.0976		
.660	1.2309	.835	1.0944		
.665	1.2263	.840	1.0911		
.670	1.2217	.845	1.0879		

TABLE 16
F_g

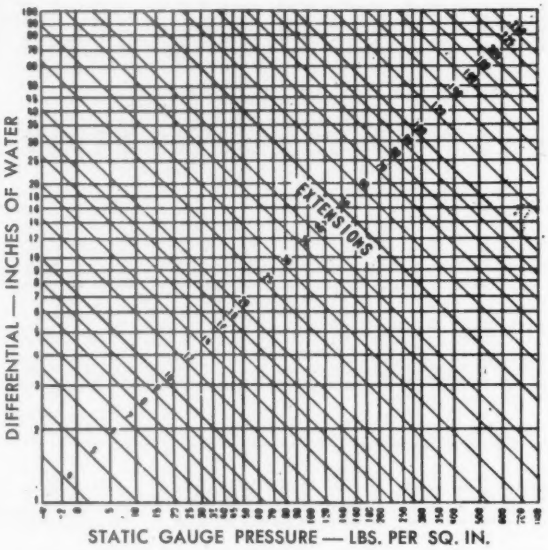
METHODS OF DETERMINING APPROXIMATE HOURLY FLOW THROUGH AN ORIFICE METER

(1) Locate differential on left margin.

(2) Trace to right to perpendicular line representing static gauge pressure on bottom scale.

(3) Read extension factor from diagonal lines.

(4) Hourly flow in cu ft = extension factor + orifice flow constants taken from tables No. XIV or XV.



Example: Assume an orifice meter with a 2 in. orifice in a 4 in. pipe run, having a differential of 40 in. and a static pressure of 200 lbs, flange taps being used.

Then: Extension = 95
Orifice flow constant = 1070
Hourly flow = 95 × 1070 = 102,000 cu ft.

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS — FLANGE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XIV

Orifice diameter inches	Pipe size 2″Std. (2.067)	3″Std. (3.068)	4″Std. (4.026)	6″Std. (6.065)	8″Std. (8.071)	10″Std. (10.136)	12″Std. (12.090)
.25	16	16	16				
.375	36	36	36				
.50	64	64	64	64			
.625	101	100	99	99			
.75	146	144	143	143			
.875	201	197	196	195	195		
1.00	267	258	256	255	254		
1.125	345	329	325	323	322	322	
1.25	438	409	403	399	398	397	397
1.375	550	499	489	484	482	481	481
1.50	688	600	585	577	574	573	572
1.625		714	690	678	675	673	672
1.75		842	805	788	783	781	780
1.875		986	931	906	900	898	896
2.00		1150	1070	1030	1030	1020	1020
2.125		1340	1220	1170	1160	1160	1150
2.25		1550	1380	1320	1300	1300	1290
2.375			1560	1470	1450	1540	1440
2.50			1760	1630	1610	1600	1600
2.625			1980	1810	1780	1770	1760
2.75			2220	2000	1960	1940	1940
2.875			2480	2190	2140	2130	2120
3.00			2790	2400	2340	2320	2310
3.125				2620	2540	2520	2510
3.25				2860	2760	2730	2710
3.375				3100	2980	2940	2930
3.50				3370	3220	3170	3150
3.625				3650	3460	3410	3390
3.75				3950	3720	3650	3630
3.875				4270	3990	3910	3880
4.00				4600	4270	4170	4130
4.25				5350	4860	4730	4680
4.50				6220	5520	5330	5260
4.75					6230	5970	5880
5.00					7020	6660	6540
5.25					7880	7400	7240
5.50					8820	8190	7980
5.75					9870	9040	8760
6.00					11000	9960	9600
6.25						10900	10500
6.50						12000	11400
6.75						13100	12400
7.00						14400	13500
7.25						15700	14600
7.50						17200	15800
7.75							17000
8.00							18400
8.25							19800

Note: The above Flow Constants are only approximate values and should not be used in Commercial Gas Measurement Computations.

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS — PIPE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XV

Orifice diameter inches	Pipe sizes 2″Std. (2.067)	3″Std. (3.068)	4″Std. (4.026)	6″Std. (6.065)	8″Std. (8.071)	10″Std. (10.136)	12″Std (12.090)
.25	16	16	16				
.375	37	36	36				
.50	67	65	65	64			
.625	107	103	101	100			
.75	159	150	147	145			
.875	225	207	202	198	197		
1.00	309	276	266	259	257		
1.125	416	357	341	330	326	325	
1.25	556	453	428	410	404	402	400
1.375	741	566	526	499	491	487	485
1.50		698	637	598	586	581	578
1.625		854	764	708	691	683	679
1.75		1040	906	829	805	795	789
1.875		1260	1070	961	929	915	908
2.00		1530	1250	1110	1060	1050	1040
2.125		1860	1460	1260	1210	1180	1170
2.25			1690	1430	1360	1330	1320
2.375			1960	1620	1530	1490	1470
2.50			2270	1820	1710	1660	1640
2.625			2630	2040	1900	1840	1811
2.75			3050	2270	2100	2030	2000
2.875				2530	2320	2230	2190
3.00				2810	2550	2440	2390
3.125				3110	2790	2670	2610
3.25				3440	3050	2900	2830
3.375				3800	3330	3150	3070
3.50				4190	3620	3410	3320
3.625				4620	3930	3690	3570
3.75				5090	4260	3980	3840
3.875				5610	4620	4280	4130
4.00				6190	4990	4600	4420
4.25					5820	5280	5050
4.50					6760	6030	5730
4.75					7840	6860	6470
5.00					9070	7780	7280
5.25					10500	8800	8150
5.50					12200	9920	9100
5.75						11200	10100
6.00						12600	11200
6.25						14100	12500
6.50						15900	13800
6.75						17800	15200
7.00						20000	16800
7.25							18500
7.50							20400
7.75							22500
8.00							24800
8.25							27400

Note: The above Flow Constants are only approximate values and should not be used in Commercial Gas Measurement Computations.

From Report No. 2, Practical Methods Committee, Appalachian Gas Measurement Short Course, School of Mines, West Virginia University, 1940.

INSTRUCTIONS FOR ACCURATE PROOF TESTING OF GAS METERS

To arrive at accurate results in proof-testing gas meters necessitates close attention to a great many details. Merely connecting the meter to a prover and passing a small quantity of air or gas through, without strict regard to the following rules, will result in an approximation only and is not a correct proof test.

To proof test a meter accurately the prover must be mathematically correct, perfectly level, duly conterpoised and adjusted so as to give uniform pressure from top to bottom during the movement of the bell in the tank. Provers are commonly adjusted to throw a pressure of one and one-half inches water column. The liquid in the prover, the air or gas in the bell and also the meter to be proof tested must all be uniform in temperature with the air of the room in which the tests are to be made and all these temperatures must be kept uniform during the entire test.

The meter or meters to be proof tested should be brought to the proving room at least five hours or if possible for a longer period before making tests, thereby giving them an opportunity to become adjusted to room temperature. When these conditions have been met, the test may proceed.

Percentage of Error Table

	2 cubic feet passed by meter		5 cubic feet passed by meter		10 cubic feet passed by meter		20 cubic feet passed by meter	
	Prover	Error	Prover	Error	Prover	Error	Prover	Error
	1.80	+11.11	4.50	+11.11	9.00	+11.11	18.00	+11.11
	1.81	+10.50	4.52	+10.62	9.05	+10.50	18.10	+10.50
	1.82	+ 9.89	4.55	+ 9.89	9.10	+ 9.89	18.20	+ 9.89
	1.83	+ 9.29	4.58	+ 9.17	9.15	+ 9.29	18.30	+ 9.29
	1.84	+ 8.70	4.60	+ 8.70	9.20	+ 8.70	18.40	+ 8.70
	1.85	+ 8.11	4.62	+ 8.20	9.25	+ 8.11	18.50	+ 8.11
	1.86	+ 7.53	4.65	+ 7.53	9.30	+ 7.53	18.60	+ 7.53
	1.87	+ 6.95	4.68	+ 6.84	9.35	+ 6.95	18.70	+ 6.95
	1.88	+ 6.38	4.70	+ 6.38	9.40	+ 6.38	18.80	+ 6.38
	1.89	+ 5.82	4.72	+ 5.93	9.45	+ 5.82	18.90	+ 5.82
Fast	1.90	+ 5.26	4.75	+ 5.26	9.50	+ 5.26	19.00	+ 5.26
	1.91	+ 4.71	4.78	+ 4.60	9.55	+ 4.71	19.10	+ 4.71
	1.92	+ 4.17	4.80	+ 4.17	9.60	+ 4.17	19.20	+ 4.17
	1.93	+ 3.63	4.82	+ 3.73	9.65	+ 3.63	19.30	+ 3.63
	1.94	+ 3.09	4.85	+ 3.09	9.70	+ 3.09	19.40	+ 3.09
	1.95	+ 2.56	4.88	+ 2.46	9.75	+ 2.56	19.50	+ 2.56
	1.96	+ 2.04	4.90	+ 2.04	9.80	+ 2.04	19.60	+ 2.04
	1.97	+ 1.52	4.92	+ 1.63	9.85	+ 1.52	19.70	+ 1.52
	1.98	+ 1.01	4.95	+ 1.01	9.90	+ 1.01	19.80	+ 1.01
	1.99	+ 0.50	4.98	+ 0.40	9.95	+ 0.50	19.90	+ 0.50
Correct	2.00	0.00	5.00	0.00	10.00	0.00	20.00	0.00
	2.01	−0.50	5.02	−0.40	10.05	−0.50	20.10	−0.50
	2.02	−0.99	5.05	−0.99	10.10	−0.99	20.20	−0.99
	2.03	−1.48	5.08	−1.57	10.15	−1.48	20.30	−1.48
	2.04	−1.96	5.10	−1.96	10.20	−1.96	20.40	−1.96
	2.05	−2.44	5.12	−2.34	10.15	−2.44	20.50	−2.44
	2.06	−2.91	5.15	−2.91	10.30	−2.91	20.60	−2.91
	2.07	−3.38	5.18	−3.47	10.35	−3.38	20.70	−3.38
	2.08	−3.85	5.20	−3.85	10.40	−3.85	20.80	−3.85
	2.09	−4.31	5.22	−4.21	10.45	−4.31	20.90	−4.31
	2.10	−4.76	5.25	−4.76	10.50	−4.76	21.00	−4.76
Slow	2.11	−5.21	5.28	−5.30	10.55	−5.21	21.10	−5.21
	2.12	−5.66	5.30	−5.66	10.60	−5.66	21.20	−5.66
	2.13	−6.10	5.32	−6.02	10.65	−6.10	21.30	−6.10
	2.14	−6.54	5.35	−6.54	10.70	−6.54	21.40	−6.54
	2.15	−6.98	5.38	−7.06	10.75	−6.98	21.50	−6.98
	2.16	−7.41	5.40	−7.41	10.80	−7.41	21.60	−7.41
	2.17	−7.83	5.42	−7.75	10.85	−7.83	21.70	−7.83
	2.18	−8.26	5.45	−8.26	10.90	−8.26	21.80	−8.26
	2.19	−8.68	5.48	−8.76	10.95	−8.68	21.90	−8.68
	2.20	−9.09	5.50	−9.09	11.00	−9.09	22.00	−9.09

The inlet of the meter is connected to the prover hose by means of a suitable connection. The connections and meter are then tested for leaks by opening the outlet valve on the prover connections, placing the palm of the hand over the meter outlet, and then closing the valve. If the siphon gauge shows a drop in pressure, it is an indication of a leak in the connection or in the meter. The leak can be located by means of soapsuds.

Attach the proper check cap on the meter outlet and pass enough air from the prover through the meter to bring the test hand, while on the up run, directly over a division or mark on the proving circle.

Fill the prover bell and carefully adjust the zero scale reading by means of the prover slide valve. Open the valve on the connection and pass a sufficient volume from the prover through the meter to cause the test hand to make one full revolution. Exercise care to insure that the test hand is stopped exactly over the mark from which it started at the beginning of the test. The reading on the prover scale is noted and from these data the proof is determined. If the meter is to be proof tested at the open rate, the procedure is the same as with the check rate test with the exception that the meter outlet is unrestricted. The maximum rate at which the prover delivers air through the hose and connections to the meter at the open-rate test depends upon the capacity of the meter, pressure in the prover, and size of connections from the interior of the prover to the meter.

Differential Test

The differential test of meters at a definite check rate is the supplementary test which is used as a final check to determine the absence of avoidable internal friction or binds in meters before final proof. For this purpose the differential, which is the difference in pressure between the inlet and outlet of the meter, is indicated in inches of water on a sensitive draft gauge.

At a very low rate of flow the differential is produced primarily by internal friction. In a properly assembled meter this internal friction depends upon the flexibility of the diaphragms, the relative tightness of the stuffing boxes, and to a certain extent, upon the clearance between the moving parts. In some cases where heavier diaphragms or tighter packing of the stuffing boxes are specified, a slightly higher differential will result. Consequently, for any particular size of meter, the differential limits will depend upon the specifications.

Any increase in differential resulting from binds, excessive friction in the stuffing boxes, or stiff diaphragm leather should be eliminated before final proof. This precaution is of basic importance because if internal friction is reduced by wear after a meter is placed in service, the proof may be affected.

At low rates of flow, the differential between meter inlet and outlet pressures may be about 0.10 inches of water.

American Meter Company, Inc.

CAST IRON AND ALUMINUM CASES

Meter cases are now made in both cast iron and aluminum. The cast iron case has been standard for many years. With the event of new types of alloys and requests for light-weight meters having all the advantages of cast iron, the aluminum alloy meter has been brought forth to meet the necessary specifications. The advantages of the aluminum case meter are, freedom from rust, requires no paint, light to handle, no fire hazard, and all parts being interchangeable with older models.

MEASUREMENT—AT HIGH PRESSURE

Gas meters always measure the gas at line pressure. It is not always practicable to reduce the pressure and measure the gas at low pressure. In many instances it would be necessary to compress the gas again to transmit it to the point of consumption.

Meters for high pressure service have the same measuring mechanism as those employed for low pressure. The only difference is in the strength of the case.

If the line pressure does not remain constant, it is necessary to equip the meter with a recording volume and pressure gauge in order to arrive at the correct base or selling pressure. The correct volume is computed from the gauge chart and a pressure table.

If the line pressure remains constant, a pressure and volume gauge is not necessary. The correct pressure factor may be taken from the table and applied directly to the meter reading.

The generally accepted average atmospheric pressure is 14.4 pounds. Gauge pressure is the difference between the absolute pressure and the atmospheric pressure, viz., the absolute pressure equals the atmospheric pressure plus gauge pressure. Absolute pressure must be used in all gas calculations involving the gas laws.

The method of converting volume measured at high pressure to volume at a base or selling pressure is as follows:

Meter Reading	215,512 cu. ft.
Atmospheric pressure	14.4 pounds per sq in.
Base pressure	4 ounces
Gauge pressure	45 pounds per sq in.

In the table under "Base pressure 4 ounces" observe the constant for 45 pounds gauge pressure. It is found to be 4.005. Multiply the meter reading by this constant to obtain the volume measured at the selling pressure, or 4.055 x 215,512 = 873,901 cu ft.

If the pressure varies, it is necessary to employ a recording volume and pressure gauge. An average pressure for the volume measured is calculated from the gauge chart. This average pressure is then interpolated in table of pressure factors and the calculations from this point are identical to those employed for a constant pressure.

Sprague Meter Company.

Pressure Factors for High Pressure Measurement

Gauge pressure pounds	Base pressure, pounds absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)	Gauge pressure pounds	Base pressure, pounds absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)
0	0.983	0.966	0.958	0.878	38	3.577	3.517	3.488	3.195
1	1.051	1.034	1.025	0.939	39	3.645	3.584	3.554	3.256
2	1.119	1.101	1.092	1.000	40	3.713	3.651	3.621	3.317
3	1.188	1.168	1.158	1.061	41	3.782	3.718	3.687	3.378
4	1.256	1.235	1.225	1.122	42	3.849	3.785	3.754	3.439
5	1.324	1.302	1.291	1.183	43	3.918	3.852	3.820	3.500
6	1.392	1.369	1.358	1.244	44	3.986	3.919	3.887	3.561
7	1.461	1.436	1.424	1.305	45	4.055	3.987	3.953	3.622
8	1.529	1.503	1.491	1.366	46	4.123	4.054	4.020	3.683
9	1.597	1.570	1.557	1.427	47	4.191	4.121	4.087	3.744
10	1.666	1.638	1.624	1.488	48	4.259	4.188	4.153	3.805
11	1.734	1.705	1.691	1.549	49	4.328	4.255	4.220	3.866
12	1.802	1.772	1.757	1.610	50	4.396	4.322	4.286	3.927
13	1.870	1.839	1.824	1.671	51	4.464	4.389	4.353	3.988
14	1.939	1.906	1.890	1.732	52	4.352	4.456	4.419	4.049
15	2.007	1.973	1.957	1.793	53	4.601	4.523	4.486	4.110
16	2.075	2.040	2.023	1.854	54	4.669	4.591	4.552	4.171
17	2.143	2.107	2.090	1.915	55	4.737	4.658	4.619	4.232
18	2.212	2.174	2.156	1.976	56	4.805	4.725	4.686	4.293
19	2.280	2.242	2.223	2.037	57	4.874	4.792	4.752	4.354
20	2.348	2.309	2.290	2.098	58	4.942	4.859	4.819	4.415
21	2.416	2.376	2.356	2.159	59	5.010	4.926	4.885	4.476
22	2.485	2.443	2.423	2.220	60	5.078	4.993	4.952	4.537
23	2.553	2.510	2.489	2.280	61	5.147	5.060	5.018	4.598
24	2.621	2.577	2.556	2.341	62	5.215	5.128	5.085	4.659
25	2.689	2.644	2.622	2.402	63	5.283	5.195	5.151	4.720
26	2.758	2.711	2.689	2.463	64	5.352	5.262	5.218	4.780
27	2.826	2.779	2.755	2.524	65	5.420	5.329	5.285	4.841
28	2.894	2.846	2.822	2.585	66	5.488	5.396	5.351	4.902
29	2.962	2.913	2.889	2.646	67	5.556	5.463	5.418	4.963
30	3.031	2.980	2.955	2.707	68	5.625	5.530	5.484	5.024
31	3.099	3.047	3.022	2.768	69	5.693	5.597	5.551	5.085
32	3.167	3.114	3.088	2.829	70	5.761	5.664	5.617	5.146
33	3.235	3.181	3.155	2.890	71	5.829	5.732	5.684	5.207
34	3.304	3.248	3.221	2.951	72	5.898	5.799	5.750	5.268
35	3.372	3.315	3.288	3.012	73	5.966	5.866	5.817	5.329
36	3.440	3.383	3.354	3.073	74	6.034	5.933	5.884	5.390
37	3.509	3.450	3.421	3.134	75	6.102	6.000	5.950	5.451

CRITICAL FLOW ORIFICE PROVERS

The critical flow orifice prover may be used for testing positive displacement meters at a pressure of 15 pounds gauge or more by passing gas or air through the meter and the orifice, and discharging it into the atmosphere.

If the proof of the meter does not change with changes in pressure (it should not) the time required for a full circle reading of the proving hand of the index will be the same for any particular orifice and any kind of gas, regardless of variations in pressure.

To test a meter under working pressure conditions, the prover is attached to a connection close to the meter outlet.

The orifice of proper size for testing the meter should be selected from a table furnished by the manufacturer showing the approximate time required for the passage of one cubic foot of air. A .500-inch orifice should be used for testing a meter at a rate of 4000 cu ft (index reading) an hour. A .250-inch orifice may be used for the low test rate.

On account of the small size of the orifice used, it is not practicable to calculate the standard air time by the measurement of the diameter of the orifice. It is always determined by test and is stamped on the outlet side of the disc by the manufacturer.

The "gas time' for a test with any orifice depends upon the size of the orifice, the ratio of specific heats of the gas, the temperature of the specific gravity.

See American Meter Company Bulletin E-8.

METHOD FOR DETERMINING REGULATOR CAPACITIES

A study of the various equations now in use for computing regulator capacities reveals the following seem to be the most practical:

(1) Where the flow is below critical velocity (regulator outlet absolute pressure being more than one half of the regulator inlet absolute pressure): $Q = K\sqrt{h\,p_0}$

(2) Where the flow is above critical velocity (regulator outlet absolute pressure being less than one half of regulator inlet absolute pressure): $Q = \frac{1}{2}\,KP_1$

Where,

Q = M Cu Ft per hour of .65 Sp. Gr. Gas at a base press. of 14.73 lbs per sq in absolute
h = Drop in pressure across regulator in lbs per sq in.
P_0 = Absolute outlet pressure in lbs per sq in.
P_1 = Absolute inlet pressure in lbs per sq in.
K = Constant, depending on regulator valve size and characteristics.

For convenience, these equations are transposed as follows:

$$Q = K \times \text{Flow Factor}$$

Graphic Charts Figures 1, 2, 3, & 4 have been prepared whereby flow factors may be read directly, depending upon the regulator inlet and outlet pressures.

The "Flow Factor" (shown on bottom scale) is equal to $\sqrt{hp_0}$, for conditions outlined under equation (1); and is equal to $\frac{1}{2}\,P_1$, for conditions outlined under equation (2). These flow factors when multiplied by factor "K" (in table) equal the recommended maximum regulator capacity.

In attempting to determine "K" factors for practical use for the different regulators in common use, it is necessary to make several compromises and assumptions which are briefly stated as follows:

(1) It is interpreted that the maximum capacity of a regulator is that quantity of gas which a regulator will deliver at a given pressure drop between its inlet and outlet flanges; that is, the regulator body is considered the unit rather than only the regulator valves or any part of the setting.

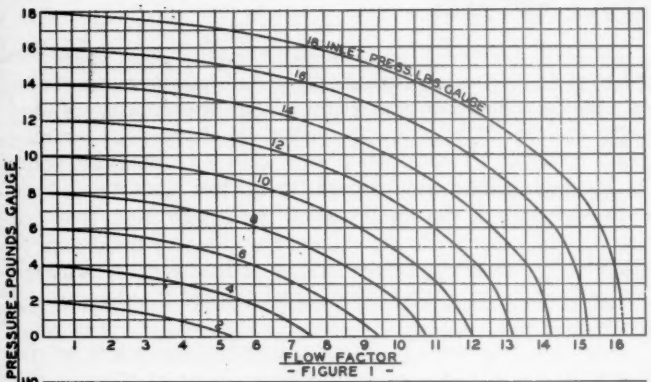
(2) In developing practical"K" factors for the different regulators, it is known that some regulators have greater valve opening areas than the area of the regulator outlet pipe opening. In such cases, the capacity should be reduced to an amount equivalent to a valve opening area equal to approximately 60 per cent of the regulator outlet pipe opening cross sectional area.

(3) These capacity data are based entirely on the capacity of the regulator main body and do not take into account variations in outlet pressure resulting from other causes, such as friction, lack of operative power, etc., which are common in the older type of regulator.

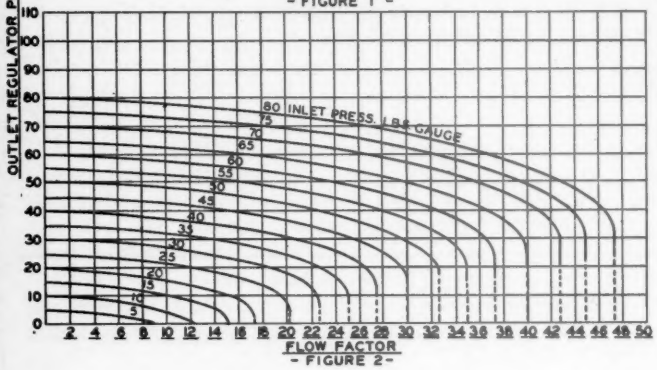
The table sets forth practical "average values" for K, which are believed to be accurate and safe for the purpose intended. In most instances they are as accurate as many of the other variables involved, such as the estimated inlet and outlet pressures, etc. Where more accurate values of "K" are available, such as those furnished by regulator manufacturers, obtained from special tests, etc., they may be substituted for those in the table and inserted in the blank spaces provided.

There may be instances where special regulators are in use and it is desired to obtain their approximate capacity. This may be done by determining the valve opening area in terms of square inches and using a "K" factor of 1.00 for each square inch, providing this area is no greater than approximately 60 per cent of the regulator outlet pipe opening. If the valve opening area is greater than 60 per cent of the outlet pipe opening, the valve opening area above this amount should be ignored. The approximate regulator capacity is then equal to "K" x Flow Factor, in the same manner as though the "K" were taken from the table.

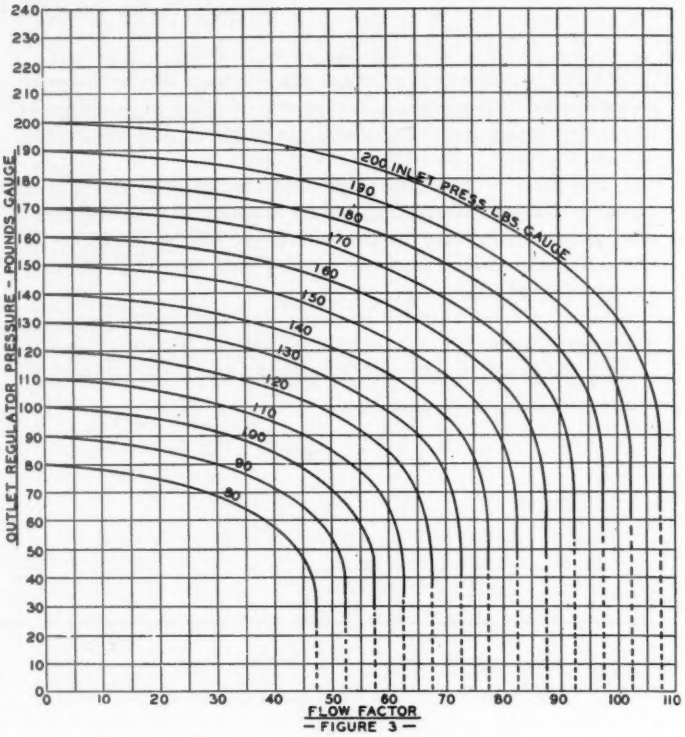
From Columbia Gas System Engineering Corporation.



- FIGURE 1 -



- FIGURE 2 -



- FIGURE 3 -

To determine Maximum Capacity of Regulator:

(1) Locate outlet pressure on left margin of graph

(2) Trace horizontally to estimated minimum inlet pressure

(3) Trace vertically down and read "Flow Factor" on bottom scale

(4) Maximum hourly capacity = Flow Factor × "K" factor

Example:

Assume—A 6″ Regulator, 25 lb. Outlet Gauge Pressure, and an estimated minimum inlet Gauge Pressure of 40 lb.

Then—From graph (Figure 2) Flow Factor = 24.5, and from table "K" Factor = 16.5
Maximum Regulator Capacity = 24.5 × 16.5 or 400 M. Cubic Feet per Hour

To determine size regulator required when the quantity and pressure conditions are known:

Example:

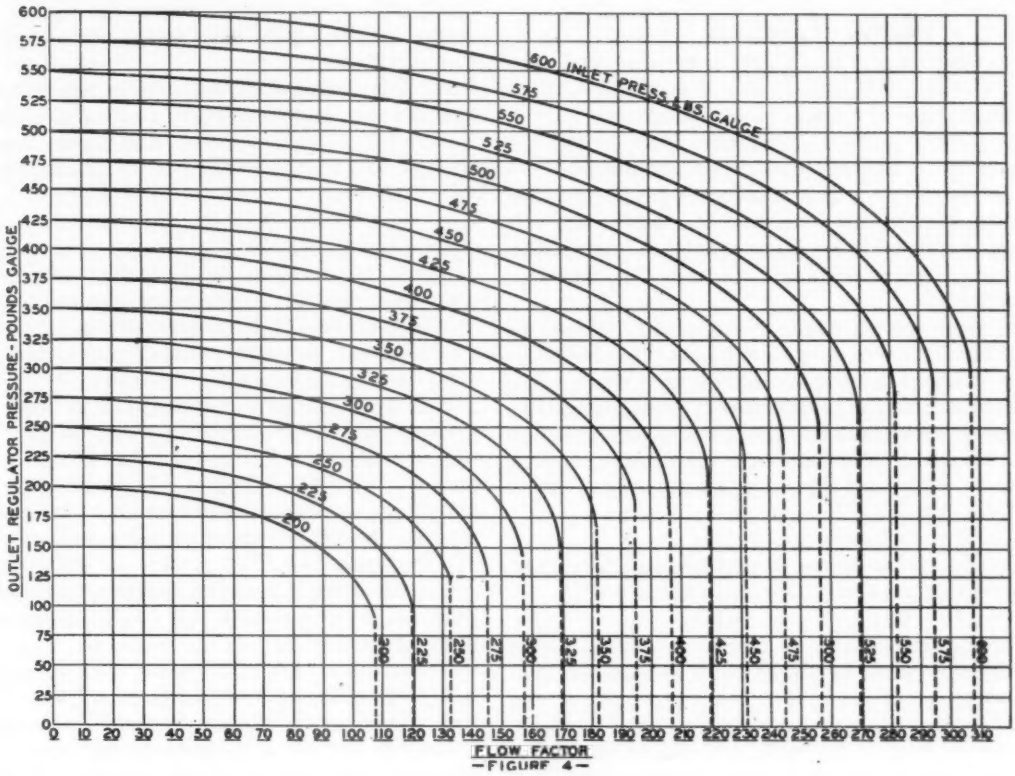
Assume—A maximum hourly rate of flow 100 M. Cu. Ft. per Hour, an Outlet Pressure of 100 lb., and an estimated minimum inlet Pressure of 250 lb.

Then—From Graph (Figure 4), Flow Factor = 133, therefore "K" Factor required = 100 ÷ 133 or .75

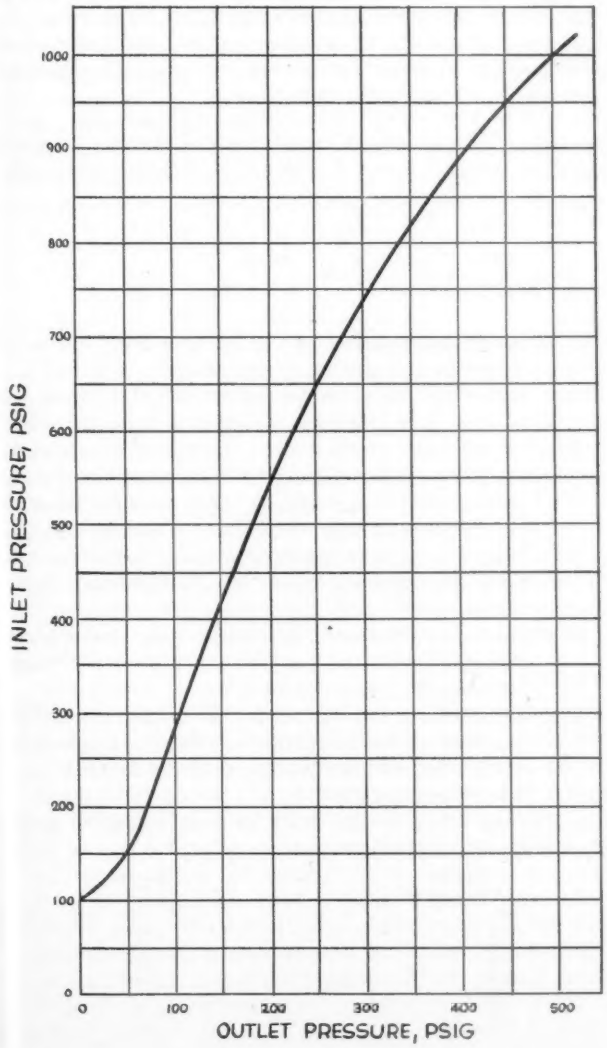
It will be noted from table shown that a 2″ regulator having 1″ balanced valves will have ample capacity.

Practical K Factors For Use In Determining Regulator Capacities

Size regulator	K factors "average values"
2″ (¾″ balanced values)	.43
2″ (1″ balanced values)	1.4
2″ (std. balanced values)	1.)
3″ (std. balanced values)	4.2
4″ (std. balanced values)	7.5
6″ (std. balanced values)	16.5
8″ (std. balanced values)	27.5
10″ (std. balancde values)	42.0
12″ (std. balanced values)	61.0



—FIGURE 4—



GUIDE FOR DETERMINING PRACTICAL PRESSURE CUT FOR SINGLE GAS REGULATOR

And Number of Cuts Required for a Station

Explanatory

Case A:

To determine the practical pressure cut for a 700 psig inlet pressure.

1 — Locate 700 psig inlet pressure on the left scale of the graph.

2 — Trace horizontally to the right to the curve and then trace vertically downward to the bottom scale. Read outlet pressure of 280 psig.

Case B:

To determine the number of cuts required for a station where the inlet pressure is 700 psig and the desired outlet pressure is to be 20 psig.

First cut — 700 psig to 280 psig.
Second cut — 280 psig to 100 psig.
Third cut — 100 psig to 20 psig.

From Columbia Gas System Engineering Corporation.

Purifier Reactions

(1) $Fe_2O_3 \cdot H_2O + 3H_2S = Fe_2S_3 + 4H_2O$.
(2) $Fe_2O_3 \cdot H_2O + 3H_2S = 2FeS + S + 4H_2O$.
Revivification of fouled oxide:
(3) $2Fe_2S_3 + 3O_2 + 2H_2O = 2Fe_2O_3 \cdot H_2O + 6S$.
(4) $4FeS + 3O_2 + 2H_2O = 2Fe_2O_3 \cdot H_2O + 4S$.

Purifier reaction (1) is the desirable one in gas purification. It occurs under alkaline conditions. The ferric sulphide (Fe_2S_3) is readily converted back to the hydrate oxide with oxygen in the presence of suitable amounts of moisture according to reaction (3).

Purification reaction (2) takes place under neutral or slightly acid conditions. The ferrous sulphide (FeS) may also be oxidized to hydrated ferric oxide according to the equation (4). The formation of ferrous sulphide is undesirable because at slightly elevated temperatures, caused by the heat given off in the reaction between oxide and H_2S, the ferrous sulphide combines with free sulphur forming iron disulphide. FeS_2 as follows:

(5) $FeS + S = FeS_2$

FeS_2 is inert and is not reoxidized to hydrated oxide. At 100° F. ferrous sulphide is oxidized to ferrous sulphate:

(6) $FeS + 2O_2 = FeSO_4$

Ferrous sulphate in the presence of water reacts acid. To correct this condition some manufacturers of purification material request that the plants submit a gallon of the fouled oxide for a complete analysis immediately after it has been discharged from the box. If the oxide is found to be sour, in other words less than a pH of 7, it is recommended that slacked lime be forked into the material before recharging it into the box. Also from the contaminate content of the oxide it can be determined whether naphthalene, cyanogen, light oils and tars are being properly removed by the gas cleaning equipment. Finally, the amount of combined sulphur present in the sample indicates whether sufficient air is being added to the gas for revivification *in situ*.

Types of "Oxide"

There are three types of oxide used for gas purification. They are Natural Irones Ores, Rusted Cast Iron Borings and Precipitated Oxides.

Capacity of Purifiers

The primary factors in purifier capacity are: time of contact and the amount of H_2S in the unpurified gas.

There are several rules or formulas for calculating purifying capacity. Some specify so many square feet of cross sectional area per unit volume of gas passed in a given time, others include the depth of oxide. A formula which allows for the several factors in the Semet-Solvay Formula, shown here.

Less complicated rules are those given by E. L. Sweeney, G. E. Seil and T. P. Keller.

Sweeney recommends a purifier capacity of 5000 bushels of active oxide, or 6000 bushels of normal oxide per million cu. ft. of maximum day output.

Seil says that it is customary to figure on 5 bushels of oxide sponge per 1000 cu. ft. of gas per day, which is substantially the same as Sweeney's recommendation.

Keller suggests purifier capacity based on 30 cu. ft. of gas per hour per bushel of oxide in each box, and recommends no less than a 4 box series in any plant operating continuously. However, in a plant where the gas temperature moisture, cleaning and other conditions are favorable, the quantity of gas handled may be as high as 100 cu. ft. per hour per bushel per box.

Miscellaneous Notes

Clean gas and clean oxide are essential to efficient purification.

Selection of oxide is largely a local matter, as there are many suitable oxides from which one may choose. The main considerations are:

1. The material should contain no metallic iron or steel and the mass should be easily permeable to the gas.
2. The concentration of iron oxide may vary from 5 pounds to 15 pounds Fe_2O_3 per bushel, depending upon local conditions.
3. Care should be taken that the oxide does not take fire or be violently heated.
4. Do not allow oxide to dry out while lying around or in the boxes. Once it becomes too dry, it is difficult to get the material to absorb the proper amount of moisture.

The activity of oxide increases with an increase in temperature. A temperature range of from 92° to 100° F. is very satisfactory. For proper removal of tar and oils it is advantageous to cool the gas to 60° F. or lower. If the gas reaches the purifiers at a temperature of 60° F. or lower, the temperature can be easily raised to 92° F. or 100° F. by introducing steam into the gas at the inlet to the purifiers. This will saturate the gas at the higher temperatures and prevent drying the oxide. At a temperature of 60° F. most oxides are quite active and if the oxide is clean it will ultimately remove more sulphur ever at 40° or 50° F. than material saturated with tar.

When oxide throws excessive back pressure, one remedy is to take off the cover of the box and remove the impervious crust. This can only be accomplished when the gas flow is in at the top and out at the bottom, and is one reason why it is distinctly advantageous to have one directional gas flow. Likewise in down flow boxes any deposition of moisture is more evenly distributed when the moisture is draining from the box in the direction of the gas flow and not counter current to it. Where an impervious layer cannot be partially removed, it is necessary to dump the entire box.

Semet-Solvay Engineering Corporation Gas Purifier Formula Based on Original Steere Engineering Company Formula

$$2A = \frac{G \times S}{3000 \times (D + C)}$$

$$G = \frac{3000 \times (D + C) \times A}{S}$$

Where:

G = maximum quantity of gas in cubic feet (corrected to 60 F) to be purified per hour.
S = factor for grains of hydrogen sulfide (H_2S) per 100 cu ft of unpurified gas, as given in the table below.
D = ½ the total depth in feet of oxide through which the gas passes consecutively in the purifier set, and is obtained by multiplying the depth of such oxide per box by the number of boxes in series in the set. Where a single "catch box" is used for two or more sets, disregard the catch box in obtaining factor "D."
A = cross sectional area in square feet of the oxide through which the gas passes on its way through any one box, in series of a set.
C = factor, 4 for two-box, 8 for three-box, and 10 for four-box series, respectively. Where a single catch box is used for two two-box sets, use factor C = 6.
3000 = assembling constant.

Factor corresponding to the value of S expressed in grains H_2S per 100 cu ft unpurified gas is:

Grains	Factor
1,000 or more	720
900	700
800	675
700	640
600	600
500	560
400	525
300	500
200 or less	480

Most oxide manufacturers will furnish oxide of various degrees of coarseness dependent upon whether the local plant condition necessitates special material due to dry gases or to tar contaminated gas.

When new or comparatively new oxide is removed from the box, it must never be left in piles, but should be spread out in layer from 12 in. to not over 18 in. deep; otherwise it may take fire. The purifier should be completely emptied and no oxide left in it over night.

The alkalinity of oxide is important for efficient purification. New material should be sufficiently alkaline to show a pH value of from 8 to 11 when put in the boxes. A pH value of 7 or more should be maintained during the total life of the material. If the alkalinity goes below 7, sulphur and iron will combine to form a compound that will not revive. Alkalinity can be maintained by adding 4 to 6 grains of ammonia per thousand cubic feet in carburetted water gas or 10 grains per thousand cubic feet of coke oven gas where cyanogen compounds do not exceed 40 grains per hundred cubic feet. Under certain conditions oxide manufacturers will recommend the addition of a wetting agent and sufficient alkali by means of a spray in the box in order to maintain an alkaline pH throughout the life of the oxide.

There are numerous inexpensive pH sets on the market so that the smallest gas plant can purchase one for not only the control of their purifying boxes, but also for their boiler water determinations.

E. L. Sweeney (A.G.A. Production Conference 1939, published in *American Gas Journal* 1939) gives the following additional notes on dry box purification.

"For economical operation a capacity of 5000 bushels of active oxide; or 6000 bushels of normal oxide, per million cubic feet of maximum day output is satisfactory.

"A flow of gas equivalent to 30-50 cu. ft. per hour per bushel of oxide in the first box is desirable. The rate of flow should be as high as possible. It depends upon the kind of oxide used and the concentration of H_2S. If the material is of normal activity, a rate as high as 50 cu. ft. per bushel of oxide in the first box can be used. A rate below 30 cu. ft. will, in most cases, eventually result in traces of H_2S passing the system. This phenomenon is more than likely due to the thickness of the water and gas film on the surface of the oxide particles which is affected by the velocity of the gas. The diffusion rate of H_2S through this film is the controlling factor.

"A mixture of approximately 2 volumes of carrier to 1 volume of ore produces a satisfactory surface area.

"The concentration of oxygen in the outlet gas should be 0.5%-1.0%.

"The activity of an oxide increases with increase of temperature, and a range between 90°-110° F. controlled with exhaust or live steam injected into the inlet gas main has been found satisfactory.

"A rise in temperature through the system usually indicates either excess oxygen, or a deficiency in moisture, sometimes both. This condition will cause the oxide to become caked, dry and inactive, except in a few instances where the gas entering is saturated and the interval of time between dumping is comparatively short."

Lead Acetate Test for Hydrogen Sulfide

The gas shall be considered free from hydrogen sulphide (H_2S) if a strip of white paper, moistened with a solution containing 5 per cent by weight of lead acetate, is not distinctly darker than a second paper freshly moistened with the same solution, after the first paper has been exposed to the gas for 1 minute in an apparatus of approved form, through which the gas is flowing at the rate of approximately 5 cu. ft. per hour, the gas not impinging directly from a jet upon the test paper.

Bureau of Standards, Circ. 32.

Sensitive Basic Acetate

50 grams of lead acetate per liter made basic with NaOH until the precipitate first formed is dissolved. This solution stains light brown at a concentration of less than 0.04 grains of H_2S per 100 cu. ft. It is about 10 times as sensitive as the standard lead acetate paper tests.

E. L. Sweeney.

DIETHYLENE GLYCOL PROCESS

It has been established that solids resembling ice or snow form under certain conditions in natural gas transmission lines operating at elevated pressures. The solids, called hydrates, are a combination of water and hydrocarbon components of the gas and restrict flow in the line and clog pressure regulators and valves. Formation of hydrates can be eliminated by dehydrating the gas entering the lines or by the use of anti-freeze agents such as methanol. Dehydration is the method commonly used today to prevent hydrate formation in long distance lines, although anti-freeze agents are occasionally used. Most pipe line companies now specify a maximum permissible water content of gas entering their transmission systems.

The glycols are noted for their hygroscopicity which is one of the characteristics that has led to their widespread industrial use. Diethylene glycol has been successfully used to dehydrate natural gas for 15 years. Triethylene glycol has been used to dehumidify air since 1939, although it has been used for natural gas dehydration only recently. Both of these high boiling point glycols are thermally stable and do not oxidize or decompose in normal plant use. Make-up requirements, are, therefore, small. The dew point depression obtainable in a glycol dehydration plant depends upon the temperature at which contact occurs, as well as the concentration of glycol in the circulated solution. More natural gas is dehydrated today by means of the glycols than by any other method.

A glycol type dehydration plant contains a minimum of equipment and inexpensive "package" units are available from several manufacturers. Many such plants do not require constant supervision and are, therefore, inexpensive to operate. The introduction of plants of this type makes possible dehydration of gas at the well head, thus eliminating the need for line heaters in field gathering systems. The glycol process consists of scrubbing the gas stream to be dehydrated with a glycol-water mixture in a plate or packed column. The dehydrated gas leaves the top of the contactor after passing through a mist extractor section. The dilute glycol solution which has removed the majority of the water from the gas stream leaves the bottom of the contactor and passes through a heat exchanger into a concentrator in which water is removed. In most plants the concentrator consists of a still provided with heat exchange surface for further heating the glycol solution and a fractionating column to reduce the loss of glycol vapor in the overhead. Heating may be accomplished by direct firing, steam or hot oil. Other methods of concentrating the solution, such as a vacuum distillation, are used in special cases. After leaving the concentrator, the glycol is heat exchanged with the incoming dilute solution, may be further cooled with water if necessary, and returned to the top of the contactor to repeat the dehydration cycle.

Carbide and Chemicals Company.

COMPARISON OF DRYING AGENTS AND DEHYDRATION PROCESSES*

Type of dehydration	Advantages	Disadvantages	Remarks
Physical and physicochemical methods: Cooling	Inexpensive where cooling water is cheap or refrigeration is available as by-product of another process	Limited degree of dehydration. Possibility of plugging cooler tubes with ice or hydrates	
Compression		Possibility of hydrate formations in cooler. Not economical unless higher pressures are necessary for some other step in processing the gas	Dehydration plants follow compressors to take advantage of this effect
Absorption			
With liquids			
Brine (35–40% $CaCl_2$)	$CaCl_2$ very cheap. Small make-up required (0.1–0.2 lb $CaCl_2$/million cu ft., 0.393 lb/million cu ft)	Danger of electrolytic corrosion (not corrosive in natural gas unless pH is below 4.2). Tends to emulsify with accumulated absorption oil, entrained oil, etc., to decrease the efficiency of contacting equipment. Available dew-point depression limited by the solubility of $CaCl_2$. Hydrogen sulfide forms objectionable precipitates	Dew-point depression of 23–31° F
Diethylene glycol 96%	Relatively stable toward gases containing oxygen, sulfur, or carbon dioxide. Good dew-point depression. No danger of solidification of concentrated solutions	0.2–0.8 lb glycol lost/million cu ft through vaporization	Dew-point depression of 40–60° F
Lithium chloride	Highly hygroscopic. Nontoxic. Not hydrolyzed on boiling. Concentrated solutions not readily solidified. Less corrosive than $CaCl_2$.	Expensive. Commercial grades of lithium chloride reported to be corrosive because of impurities	Dew-point depression of 40–67° F
Glycerin 85%		Expensive. Tends to decompose on regeneration. At concentrations above 85%, it becomes too viscous for easy handling and foams easily	Dew-point depression of 30–33° F. Used in manufactured gas plants aboard
Zinc chloride	High dew-point depression	Possible acid corrosion	Dew-point depression of 40–55° F
Calcium chloride, 40%. Glycerin 20%	Inhibits crystallization of $CaCl_2$, allowing greater dew-point depression than straight $CaCl_2$	Hydrogen sulfide forms iron sulfide and causes foaming. Corrosive	Dew-point depression of 23–41° F. 0.02 to 0.06 gal. of make-up/million cu ft on unit treating 110–130 million cu ft/day at 200 psi
Dow 8A ($CaBr_2$-$CaCl_2$ and/or $CaBr_2$)	High dew-point depression	Corrosive	Dew-point depression of 29–64° F
Amine, glycol, water, 7–8% monoethanolamine, 75–80% diethylene glycol, 12–16% water	Simultaneous removal of water, carbon dioxide, hydrogen sulfide, and other acid gases. Greater dew-point depression than glycol alone. Glycol reduces foaming tendencies of the amine	Amines volatilize and may be adsorbed on solid desiccants used in subsequent processing, necessitating occasional washing of the desiccant	Approximately 0.1 gal/million cu ft make-up required
With solids			
Lump $CaCl_2$. Molded from water, $CaCl_2$ and pulverized minerals or molten 72% $CaCl_2$ solution. Addition of pulverized carbon adds odor adsorption	Inexpensive. High capacity. Simple equipment required	Disintegrates in water, obstructing gas flow. Corrosive. Efficiency of dehydration varies with amount of water absorbed. Generally discarded when once exhausted	
Lump KOH, NaOH	(same advantages and disadvantages as lump $CaCl_2$)		Used for liquefied petroleum gases
Adsorption. Granular adsorbents in general (silica gel, activated alumina, activated $CaSO_4$, activated bauxite, Florite Desiccant)	Good drying efficiency. Not corrosive. Easily regenerated. Easily handled.	Drying unit is cyclic rather than continuous. May be plugged or disintegrated by contaminants. Relatively high heat requirements for regeneration	Dew-point depression of 100° F or more
Chemical methods: Phosphorus pentoxide, P_2O_5	Highest drying efficiency. Good capacity	Difficult to handle. Corrosive Becomes wet and sticky when saturated. Strongly acid.	Not used on large-scale gas drying
Barium oxide, BaO. Precipitated by heating $BaCO_3$	Will dehydrate at temp up to 1000° F. Cheap. Granular. Easily handled. Efficiency practically equal to P_2O_5. Large capacity.	Expands on hydration. Cannot be regenerated. Strong alkali.	
Magnesium perchlorate (anhydrous; trihydrate)	Anhydrous form reported to have efficiency of P_2O_5. Large capacity. Contracts on adsorbing water. Chemically neutral.	Not suitable for flammable or acid gases (reacts to form explosive perchloric acid	
Magnesium oxide, MgO	High activity	Low capacity	Not used on large-scale gas drying
Unslaked lime, CaO	High capacity	Corrosive. Hard to handle	
Combination methods: Combined absorption-adsorption (HiFlorite, alumina, $CaCl_2$, impregnated Drierite, etc.)	Relatively high capacity. Good efficiency	Loss of impregnated salt at high moisture saturation. Higher initial cost of disiccant. Corrosive (depending on nature of impregnated salt)	
Combined use of refrigeration and liquid absorbent	Higher dew-point depression than absorbent alone. Less danger of freeze-ups than refrigeration alone	Must be preceded by gasoline plant on natural-gas systems to prevent formation of condensate. relatively complex plant operation	

*Amero, Moore, and Cappell, *Chem. Eng. Progress*, April, 1947. Reproduced by permission of the authors, the Floridin Company, Warren, Pa., and the AIChE.

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GAS ODORANT CHARACTERISTICS

Information furnished by manufacturers

Odorant Characteristic	Natural Gas Odorizing Co., Inc.	Sharples Chemicals, Inc.			
	Captan	Spotleak no. 1008	Spotleak no. 1009	Pentalarm no. 86	Pentalarm no. 1004
Specific gravity	0.835	0.83	0.81	0.84	0.84
Molecular wt., av. of mercaptans present	—	77	88	104	88
Weight/gal., lbs	7.0	6.7	6.7	7.0	7.0
Viscosity, centistokes—at 60° F.	0.548	—	—	—	—
—at 77° F.	—	0.53	0.64	0.69	0.58
Reid vapor press., at 100° F, psi	5.0	5.3	4.9	1.5	8.8
Distillation	Start 125° F	—	—	—	—
	95% 265° F	—	—	—	—
	End 340° F	—	—	—	—
——°F, 2%	—	120	120	221	122
——°F,95%	—	270	180	266	240
Volatility, lbs/MMcf		70 psi 700 psi	70 psi 800 psi	70 psi 700 psi	70 psi 700 psi
—40%	—	2,400 240	3,800 380	500 50	520 52
—80%	—	6,800 680	11,000 1,100	1,760 176	1,880 188
Freezing point, °F	—	←—50	←—50	←—50	←—50
Flash point, open cup, °F	—	◀0	◀0	50	◀0
Mercaptan cont., % by wt	94	94	94	90	94
Mercaptan sulfur cont., % by volume	33	33	35	28	34
Toxicity at normal concentration	—	negligible	negligible	negligible	negligible
Solubility in water, % mercap. sulf. content in sat. sol. at 77° F	—	0.060	0.040	0.010	0.015
Recommended odor.-rate, lbs/MMcf	0.25–1.00	0.25–1.00	0.25–0.75	0.50–1.50	0.50–1.25
Sulfur contribution at rec. rate, grains/100 cf	—	0.058–0.232	0.06–0.183	0.098–0.294	0.120–0.300

Odorant Characteristic	Oronite Chemical Company			
	Calodorant	Calodorant "C"	Calodorant "C" Special	Alert "80"
Specific gravity	0.78	1.0	0.878	0.830
Molecular weight	—	88	104	—
Weight/gal., lbs	6.5	8.34	7.31	6.9
Viscosity, centistokes, 77° F	0.70	0.94	0.82	0.48
—32° F	0.95	1.33	—	0.55
— 0° F	1.2	1.85	—	0.66
Reid vapor press., at 100° F, psi	3.0	—	—	9.0
Distillation (ASTM D-86)				
50% recovered	230° F	—	250° F	—
70% recovered	260° F	—	275° F	—
90% recovered	309° F	—	330° F	—
End point	360° F	263° F	360° F	—
Recovered	99%	—	—	—
Flash point	29° F	64° F	—	—
Freezing point	—	—102° C	—	—
Solubility in water, % by vol	0.05	0.07	—	—
Sulfur contribution, grains/100 cf	0.41	—	—	—
at 2 gals/MMcf	—	0.12	—	—
at ½ lb/MMcf	—	—	0.14	—

ANALYSES OF COAL TYPES FREQUENTLY USED IN, OR SUITABLE FOR BY-PRODUCT COKE OVENS[1]

Name of coal	Proximate analysis (on coal as received)			Ultimate analysis (on dry coal)					Btu value (dry coal)	Estimated coke yield (total), per cent on coal as received	Estimated gas yield, Btu in gas per lb coal
	Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen			
Pennsylvania:												
Connellsville[2]	2.40	31.00	61.38	7.22	78.50	4.67	6.82	0.97	1.62	14,230	71.0	3,100
Lower Connellsville	2.00	32.20	58.00	7.80	77.80	5.20	6.33	1.09	1.63	14,100	70.0	3,200
Westmoreland	1.00	35.00	57.60	6.40	79.60	5.36	6.14	0.90	1.60	14,320	68.0	3,350
Pittsburgh[3]	3.03	35.22	55.36	6.39	79.45	5.34	5.94	1.23	1.45	14,230	68.5	3,300
Freeport[2]	2.66	34.35	56.42	6.57	79.13	5.34	6.18	1.02	1.58	14,180	69.0	3,300
Somerset (Orenda)[2]	3.77	16.26	71.06	8.91	81.96	4.15	2.22	0.81	1.60	14,075	81.0	2,600
Clearfield—Cambria (Lower Kittanning)[2]	2.00	21.17	70.90	5.93	84.10	4.60	2.72	1.23	1.42	14,800	78.5	2,680
West Virginia:												
Boomer[2]	2.96	33.57	59.18	4.29	82.45	5.32	5.36	0.80	1.65	14,840	69.0	3,300
Cabin Creek (Kanawha)	2.70	31.30	59.79	6.21	80.38	4.69	6.79	0.59	1.17	14,600	71.0	3,300
No. 2 gas[2]	2.52	34.86	56.42	6.20	80.86	5.15	5.16	0.87	1.60	14,500	69.0	3,300
Fairmont[2]	2.51	37.66	53.25	6.58	78.63	5.29	6.56	1.23	1.54	14,130	66.0	3,350
Pocahontas[2]	2.60	16.39	76.38	4.63	86.79	4.22	2.33	0.78	1.13	15,020	81.0	2,650
New River[2]	3.51	24.76	69.00	2.73	86.08	4.95	3.91	0.60	1.63	15,220	75.0	2,750
Elkins[3]	1.40	26.40	62.92	9.28	79.03	4.74	3.85	1.52	1.45	14,020	75.0	2,850
Virginia:												
Tasewell Co. (Seaboard)[2]	3.13	29.00	61.77	6.10	82.63	4.82	4.23	0.60	1.42	14,670	71.0	3,100
Toms Creek[2]	2.29	32.87	59.62	5.22	82.67	5.05	4.78	0.55	1.61	14,810	70.0	3,200
Wise Co. (Roda)	2.00	34.90	60.90	2.20	84.50	5.27	5.85	0.55	1.63	14,990	69.0	3,300
Eastern Kentucky:												
Elkhorn[2]	2.91	36.33	57.53	3.23	82.26	5.49	6.71	0.57	1.64	14,650	66.0	3,450
Coxton[3]	3.18	37.21	56.30	3.31	81.50	5.30	7.10	0.96	1.72	14,620	65.0	3,450
Benham[3]	2.50	37.52	57.63	2.35	83.01	5.42	7.07	0.53	1.56	14,960	65.5	3,500
Tennessee:												
Jellico[3]	3.87	38.03	55.18	2.92	80.34	5.54	7.90	1.13	2.05	14,250	63.0	3,400
Alabama:												
Pratt Seam[3]	2.20	28.83	62.88	6.09	81.69	4.97	3.86	1.66	1.59	14,550	72.0	3,000
Tuscaloosa[3]	2.62	24.18	64.11	9.09	79.61	4.55	4.33	0.66	1.52	14,090	75.0	2,700
Illinois:												
Franklin Co. (Orient)[3]	9.93	33.13	48.77	8.17	74.47	4.84	9.22	0.83	1.57	13,200	61.0	2,900
Indiana:												
Ayrshire[3]	12.31	35.05	46.54	6.10	75.87	5.19	9.15	1.11	1.72	13,530	60.0	2,950
Colorado:												
Trinidad[3]	4.29	36.51	52.03	7.17	77.24	5.12	8.09	0.61	1.45	13,670	64.0	3,150
Utah:												
Sunnyside[3]	4.06	37.99	49.89	8.06	74.95	5.43	8.49	1.20	1.53	13,380	63.0	3,200
Washington:												
Roslyn	3.77	37.69	47.05	11.49	72.92	5.36	7.71	0.49	1.58	13,262	63.0	3,100

Most of these analyses except where noted are of face samples taken in the mine; usually car deliveries to the consumer run 2% to 3% higher in ash.
[1] Prepared by Dr. H. C. Porter, Consulting Engineer, Philadelphia.
[2] Mine sample, analysis by U. S. Bureau of Mines.
[3] Car sample, average of 10 cars, analysis by U. S. Bureau of Mines.

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PRODUCTS OF HI AND LOW TEMPERATURE CARBONIZATION

Yields of High Temperature, Low Temperature and Complete Gasification Processes

Process	Yield ammonium sulphate	Yield light oil benzol tobol, xyol	Yield tar	Yield gas	Yield coke
High temperature Distillation	20–24 lbs. Per ton	3 plus gals. Per ton	8–12 gals. Per ton	10,000–11,500 Cu. ft. per ton 500–560 Btu per cu. ft.	1300–1400 lbs. per ton Suitable for metallurgical processes and domestic fuel
Low temperature Distillation	16–20 lbs. Per ton	3–5 gals. Per ton	20–28 gals. Per ton	5000–6000 Cu. ft. Per ton 500 to 900 Btu per cu. ft.	1400 lbs. plus per ton Domestic fuel may have to be briquetted
Complete Gasification	75 lbs. Per ton	1 gal. plus Per ton	25 gals. Per ton	100,000 Cu. ft. plus Per ton below 200 Btu's per cu. ft.	None

AVERAGE FLUE GAS DEW POINT FOR VARIOUS FUELS*

Fuel	Average dew point (temperature, °F)
Anthracite	68
Semi-bituminous coal	84
Bituminous coal	93
Oil	111
Natural gas	127
Manufactured gas	137
Propane (2,500 Btu per cu. ft)	119
Butane gas (3,200 Btu per cu. ft)	124
Butane-air gas mixture (535 Btu per cu. ft)	121

* American Society for Testing Materials.

OPERATING RESULTS, BY-PRODUCT COKE OVENS[1]

	Utica	Philadelphia
Coal used, per cent volatile matter (ash- and moisture-free)[2]	37.8	30.1
Coal charge, tons	6.86	17.9
Coking time (avg.), hr (gross)	12.6	16.46
Width of ovens (avg.), in.	13½	17¼
Coke yield, per cent dry	70.2	74.0
Gas, cu ft per lb dry coal	5.66	5.36
Gas, Btu per cu ft	584	577
Gas, Btu per lb dry coal	3,305	3,093
Producer fuel, dry, per ton coal, lb	292	215
Producer fuel, combustible, per ton coal, lb	253	200
Producer fuel used, cu ft per lb coal (at 130 Btu)	9.99	7.52
Yield tar, gal per ton	12.35	8.16
Yield sulphate, lb per ton	24.68	20.92 (Diluted with 11% producer gas)
Gas analysis:		
CO_2, per cent	2.2	1.8
Ill., per cent	4.0	3.3
O_2, per cent	0.8	0.3
CO, per cent	6.3	8.5
CH_4, per cent	32.1	24.7
H_2, per cent	46.5	51.0
N_2, per cent	8.1	10.4
	100.0	100.0

Data assembled by H. C. Porter, Philadelphia.

[1]Actual plant data submitted by The Koppers Company, Pittsburgh, Pa., for two plants, Utica, N. Y. (consisting of 21 small-size ovens built in 1924), and Philadelphia, Pa. (consisting of 74 large-size ovens built in 1928), both plants being Becker type Koppers ovens, fired by producer gas. The Utica results are taken from the official report of A.G.A. Carbonization Plant Tests made in 1925 for comparison of different types of plant, operating on the same coal. The Utica ovens were the first of their size and type to be built and on that account were not operating at the time to the best advantage. The Utica results cover a period of 21 days. The Philadelphia results are averages for a five-month period.

[2]At Utica, 100 per cent volatile Pittsburgh coal; at Philadelphia a mixture averaging 76 per cent Powellton (W. Va.) and 24 per cent Pocahontas.

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CALCULATING HEATING VALUE OF COAL FROM ANALYSIS

By far the most satisfactory way of determining the heating value of a coal is by the bomb calorimeter. Where only the analysis is available the following computations of the approximate heating value of the coal may be made.

Ultimate Analysis:

$$\text{Btu per lb} = 146\,C + 620\left(H - \frac{O}{8}\right) + 40.5\,S$$

where

C = per cent of carbon.
H = per cent of hydrogen.
O = per cent of oxygen.
S = per cent of sulfur.

With bituminous and anthracite coals and calculated values will usually be within 1½ per cent of the observed value. The higher the percentage of oxygen the greater is the error apt to be.

Proximate Analysis:

$$\text{Btu per lb} = (C \times c + V \times v) - (16\,M + 30\,A + 39\,S)$$

where

C = per cent of fixed carbon.
V = per cent of volatile combustible.
M = per cent of moisture.
A = per cent of ash.
S = per cent of sulfur.
c — see Table I.
v — see Table II.

TABLE I Values of c.

For Anthracite Coal	141
For Bituminous Coal	140
For Lignite	95
For Coke	130

Table II Values of v .

Per cent vol. comb.	"v"	Per cent vol. comb.	"v"
1	240.5	27	180.5
2	236.4	28	178.8
3	232.5	29	177.2
4	228.8	30	175.5
5	225.3	31	173.9
6	221.9	32	172.3
7	218.6	33	170.7
8	215.4	34	169.2
9	212.3	35	167.8
10	210.3	36	166.6
11	208.3	37	165.5
12	206.4	38	164.4
13	204.6	39	163.3
14	202.7	40	162.2
15	200.9	41	161.1
16	199.2	42	160.0
17	197.5	43	158.9
18	195.7	44	157.8
19	194.0	45	156.7
20	192.3	46	155.6
21	190.6	47	154.5
22	188.9	48	153.4
23	187.2	49	152.3
24	185.5	50	151.2
25	183.8	51	150.1
26	182.1	52	149.0

H. H. Clark—American Gas Light Journal.

ANALYSES AND PHYSICAL PROPERTIES OF PETROLEUM OILS

Source or name	Gravity, °Be	Sp gr 60°/60°F	Analysis C	H	O and N	S	H_2O	Btu per lb	Flash point, open cup, °F	Fire point, °F	Viscosity Saybolt seconds at 70°F	Engler scale at 68°F
Crude oils:												
Western	14.4	0.970	85.64	11.37	0.84	1.06	...	18,478	192	...	387	.....
Kern River, Calif.	15.0	0.966	.....	.....	....	0.89	0.5	18,500	102	128	...	690.0
Summerland, Calif.	15.1	0.965	.....	.....	....	0.36	1.2	18,530	100	130	...	222.1
Los Angeles City, Calif	15.4	0.963	.....	.....	....	0.62	1.7	18,430	107	145	...	272.5
Salt Lake, Calif.	15.7	0.961	.....	.....	....	2.29	0.9	18,230	46	89	...	574.3
Western	16.4	0.957	86.58	14.61	0.74	0.82	...	18,613	172	...	380	.....
Western	17.4	0.950	86.37	11.30	1.14	1.60	...	18,727	230	...	250	.....
Sunset, Calif.	18.1	0.946	.....	.....	....	0.89	0.5	18,605	47	79	...	120.5
Coalinga, Calif.	19.4	0.938	.....	.....	....	0.48	0.4	18,550	70	93	...	80.7
Whittier, Calif.	19.4	0.938	.....	.....	....	0.61	0.0	18,810	46	84	...	34.6
Lompoc, Calif.	20.0	0.934	.....	.....	....	3.55	0.7	18,330	—1	21	...	62.5
Midcontinent	20.2	0.933	86.06	11.21	2.06	0.67	...	19,440	273	...	220	.....
Midway, Calif.	20.5	0.931	.....	.....	....	0.66	0.6	18,710	54	83	...	91.7
Texas	21.6	0.924	84.60	10.90	2.87	1.63	...	18,977	60	...	...	.....
Newhall, Calif.	22.1	0.921	.....	.....	....	0.35	0.2	18,890	60	83	...	118.2
Midcontinent	22.4	0.920	84.60	10.90	2.87	1.63	...	19,060	180	...	198	.....
Fullerton, Calif.	22.5	0.919	.....	.....	....	0.89	0.2	18,800	18	52	...	110.5
Pennsylvania	23.3	0.914	86.10	13.90	....	0.60	...	20,752	...	...	...	.....
Midcontinent	24.2	0.909	87.93	11.27	0.19	0.41	...	19,650	264	...	188	.....
Coyote Hills, Calif.	24.9	0.905	.....	.....	....	1.14	tr.	18,965	27	50	...	10.5
Santa Fe Springs, Calif.	34.8	0.851	.....	.....	....	0.45	...	.....	...	...	50	.....
Santa Fe Springs, Calif.	27.9	0.888	.....	.....	....	0.54	...	.....	...	...	105	.....
Santa Maria, Calif.	24.9	0.905	.....	.....	....	1.93	0.1	18,710	—2	20	...	19.0
Santa Paula, Calif.	25.5	0.901	.....	.....	....	0.54	0.5	18,840	6	18	...	5.8
Sespe, Calif.	26.6	0.895	.....	.....	....	0.34	0.4	18,990	18	40	...	10.8
Eastern	31.9	0.866	86.40	12.37	1.02	0.13	...	19,890	102	...	165	.....
Kansas	31.9	0.866	85.40	13.07	....	....	...	20,345	...	...	...	.....
West Virginia	36.8	0.841	84.30	14.10	1.60	....	...	20,818	...	...	...	.....
Pennsylvania	37.2	0.839	.....	.....	....	....	...	20,560	128	180	...	.....
Ohio	39.4	0.829	85.00	13.80	0.60	0.60	...	20,752	...	...	...	.....
Eastern	40.4	0.823	82.00	14.80	3.20	0.10	...	20,300	78	...	112	.....

									Closed cup		Saybolt seconds	at °F
Fuel oils:												
Mexican	10.0	1.000	88.05	7.58	1.00	3.28	...	17,500	374	...	322	250
Bakersfield, Calif.	11.1	0.992	.....	.....	....	....	1.3	18,257	...	...	...	.....
Mexican	11.9	0.987	86.90	9.36	....	3.16	...	18,050	310	...	300	250
Los Angeles, City, Calif.	13.4	0.977	.....	.....	....	....	0.4	18,280	...	...	...	.....
Bakersfield, Calif.	13.6	0.975	.....	.....	....	....	...	17,600	.....	...	...	.....
California	13.6	0.975	.....	.....	....	2.46	1.3	18,104	...	...	...	.....
Mexican	14.1	0.971	85.26	10.31	....	3.94	...	18,260	208	...	92	220
California	15.0	0.966	81.52	11.61	6.92	0.55	...	18,926	...	...	...	.....
Los Angeles City, Calif.	16.4	0.957	.....	.....	....	....	...	18,855	196	...	...	.....
Midcontinent	16.7	0.955	88.22	10.16	3.74	2.83	...	18,427	190	...	74	220
Kern River, Calif.	17.4	0.950	.....	.....	....	....	...	18,845	140	...	...	.....
Whittier, Calif.	17.9	0.947	.....	.....	....	....	...	17,822	148	208	...	.....
Western	18.1	0.946	86.11	11.81	1.20	0.67	...	18,790	186	...	750	100
Whittier, Calif.	18.4	0.944	.....	.....	....	1.98	1.1	18,507	...	...	...	.....
Beaumont, Texas	18.7	0.942	86.1	12.3	....	1.60	...	20,152	...	...	...	.....
Sabine, Texas	19.5	0.937	.....	.....	....	....	...	18,662	143	...	...	.....
Whittier, Calif.	19.7	0.936	.....	.....	....	0.72	1.1	18,240	...	...	...	.....
Saratoga, Texas	20.6	0.930	.....	.....	....	....	...	19,665	180	242	...	.....
Coalinga, Calif.	21.1	0.927	.....	.....	....	....	...	17,117	134	...	...	.....
Humble, Texas	21.3	0.926	.....	.....	....	....	...	19,649	166	214	...	.....
Beaumont, Texas	21.6	0.924	84.6	10.9	2.87	1.63	...	19,060	180	...	...	.....
Spindle Top, Texas	22.0	0.922	.....	.....	....	....	...	19,663	165	219	...	.....
Mexican	22.1	0.921	.....	.....	....	....	...	18,840	162	...	...	.....
Saratoga, Texas	22.4	0.920	.....	.....	....	....	...	19,263	161	226	...	.....
Humble, Texas	22.4	0.920	.....	.....	....	....	...	18,040	124	228	...	.....
Midcontinent	22.4	0.920	83.26	12.41	3.83	0.59	...	19,430	181	...	389	100
Spindle Top, Texas	22.6	0.918	.....	.....	....	....	...	19,720	163	212	...	.....
Texas	24.0	0.910	87.29	12.32	....	0.43	...	19,659	375	...	...	.....
Texas	24.3	0.908	87.15	12.33	....	0.32	...	19,338	370	...	...	.....
Midcontinent	24.5	0.907	85.40	13.07	1.12	0.15	...	19,235	179	...	350	100
Louisiana	24.7	0.906	.....	.....	....	....	...	19,908	192	219	...	.....
Louisiana	24.9	0.905	.....	.....	....	....	...	20,193	194	233	...	.....
Beaumont, Texas	25.2	0.903	.....	.....	....	....	...	19,349	222	...	...	.....
Kansas	25.5	0.901	.....	.....	....	....	...	18,714	157	208	...	.....
California	27.3	0.891	.....	.....	....	....	...	18,655	257	...	...	.....
Pennsylvania	27.8	0.888	.....	.....	....	....	...	19,700	232	280	...	.....
Pennsylvania	28.0	0.886	84.9	13.7	1.4	....	...	19,210	...	...	...	.....
Midcontinent	28.6	0.884	84.90	13.70	1.40	0.37	...	19,312	175	...	290	100
Colorado	29.1	0.881	.....	.....	....	....	...	18,103	164	205	...	.....
Kansas	30.6	0.870	.....	.....	....	....	...	19,210	130	181	...	.....
Indiana	32.1	0.865	.....	.....	....	....	...	19,400	212	318	...	.....
Midcontinent	32.3	0.864	84.82	13.09	2.05	0.36	...	19,511	160	...	76	100
Midcontinent	35.9	0.845	84.36	13.21	1.09	0.32	...	19,627	154	...	42	100
West Virginia	36.8	0.841	84.3	14.1	1.6	....	...	21,240	...	...	...	.....
Pennsylvania	37.6	0.837	.....	.....	....	....	...	19,700	232	280	...	.....
Asphalt oil	13.4	0.977	.....	.....	....	....	...	20,442	...	376	...	.....
Gas oil	16.2	0.958	86.16	9.05	3.06	0.30	...	16,960	195	...	98	220
Steamer oil	21.1	0.927	.....	.....	....	....	...	29,291	268	322	...	.....
Kerosene, 150°	47.4	0.791	85.16	14.33	0.51	....	...	19,922	110	...	...	.....
Oil tar	....	1.150	92.00	6.13	0.22	0.33	...	17,300	485	...	418	220
Coal tar	....	1.250	89.20	4.95	5.27	0.56	...	15,800	530	...	490	220

[1] Compiled from Gebhardt, "Steam Power Plant Engineering"; Babcock & Wilcox Company, "Steam"; Heine Safety Boiler Company, "Steam Boiler Engineering"; Report of Committee on Petroleum, 1917; Rufus T. Strohm, "Oil Fuel for Steam Boilers."

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CHARACTERISTICS OF CARBURETING OILS[1]

Sample designation	Gas oil (A)	Gas oil (B)	Gas oil (C)	Heavy oil (1)	Heavy oil (2)	Heavy oil (3)	Heavy oil with some cracker tar (4)	Heavy oil containing cracker tar (5)
A.P.I. gravity at 77°F	35.1	32.5	30.3	21.1	17.2	15.4	17.3	13.9
Coke, per cent	0.22	0.62	0.02	3.98	9.05	7.10	4.62	4.11
Sulphur, per cent	....	....	....	1.18	2.77	0.60	0.98	0.58
Distillation test:								
Per cent by volume								
Below 400°F	1.3	1.4	0.9					
400 to 450	15.8	7.0	10.0					
450 to 500	26.0	15.3	26.0	.....	0.6	.....	4.5	3.9
500 to 550	20.9	18.9	31.9	1.6	2.9	2.0	11.0	12.4
550 to 600	14.8	17.4	16.7	5.2	5.6	4.3	12.4	16.0
600 to 650	8.6	13.3	8.3	9.1	22.2	12.1	16.1	15.4
650 to 700	6.7	9.5	2.5	26.8	24.2	31.9	14.4	16.0
700 to 750	5.6	8.2	3.5	14.0	.....	32.1	30.0	20.2
Residue and loss	0.3	2.0	0.2	43.3*	44.5†	17.6	11.6	16.1
Below 600°F	78.8	60.0	85.5	6.8	9.1	6.3	27.9	32.3
Above 600°F	20.9	38.0‡	14.3	49.9	46.4	66.1	60.5	51.6
Hydrocarbon test:								
Per cent by volume								
Paraffins	73.0	45.0	44.6	49.0	32.0	34.9	48.3	35.7
Napthenes	9.0	19.0	43.0	23.0	48.0	36.3	21.7	27.9
Aromatics	4.0	10.0	8.0	8.4	0.8	12.0	12.0	14.4
Olefins	14.0	26.0	4.4	19.6	19.2	16.8	18.0	22.0
Saturated compounds	82.0	64.0	87.6	72.0	80.0	71.2	70.0	63.6
Aromatics and unsaturates	18.0	36.0	12.4	28.0	20.0	28.8	30.0	36.4
Cracking test:								
Optimum temperature, °F	1330–1390	1380–1425	1380–1410	1350–1500	1350–1450	1300–1450	1350–1450	1300–1425
Btu in gas per gal	104,000	101,500	96,500	108,100	96,900	96,000	84,000	74,500
Btu of oil per cu ft	1,750	1,750	1,595	1,775	1,870	1,741	1,705	1,770
Cu ft of oil gas per gal	59.5	58.0	60.5	60.8	51.8	55.1	49.3	42.0

[1]Jerome J. Morgan, "American Gas Practice."
*Begins to crack at 705 F.
†Decomposes at 672 F.
‡Includes 7.0 per cent distilling between 750 and 817 F.

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GAS OIL EFFICIENCY

Where gas oil is used for enriching carburetted water gas and no blow-run is made the following formula is generally employed to show the enriching value of the oil in Btu per gallon.

$$\text{Btu per Gal} = \frac{1000\,(F - B)}{G} + OB$$

where

F = Btu per cu ft of the finished carburetted water gas.

B = Btu per cu ft of the blue gas. (In lack of definite information frequently assumed to be 300.)

G = Gallons of oil per thousand cubic feet.

O = Cubic feet of oil gas produced per gallon of oil. (This is generally from 65 to 70 cu ft.)

CALCULATION OF TERZIAN FACTORS FOR CARBURETTED WATER GAS MADE WITH HEAVY OIL

The development of the heavy oil process for making carburetted water gas has necessitated the conducting of plant scale tests under varied operating conditions. From the study of the operating restults of these tests, a formula called the "Terzian Factor" was developed for the comparing operating results, and has been successfully used. The formula for the "Terzian Factor" is:

$$\text{Terzian Factor} = \frac{K}{A} = \frac{10\,F + 100\,C}{A}$$

Where K = 10 F + 100 C
F = Gen Fuel used, Lb/Mcf
C = Oil used, Gal/Mcf
A = Btu per cu ft Make Gas

When operating with a fairly uniform fuel and oil, operating results obtained under extremely varying conditions of operations can be successfully compared by the use of this formula; the smaller the numerical value of the Terzian Factor, the better gasification efficiencies.

It has been found in practice that the Terzian Factor, or the relation of K to the make gas Btu is practically constant under varying operating conditions, and varying amounts of generator fuel per Mcf, when producing a carburetted water gas of 400 to 700 Btu per cu ft calorific value, and operating with heavy oil of a fairly uniform quality.

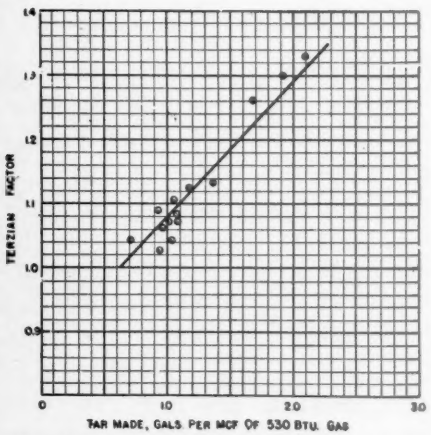
A study of heavy oil operating results of various plants for the last six years indicates that we can use the "Terzian Plant Constant" as a means of checking the plant operating results including the tar production. The formula for the "Plant Constant" is:

$$\text{Terzian Plant Constant} = \frac{K_1}{A} = \frac{10F + 100(C\text{-}T)}{A}$$

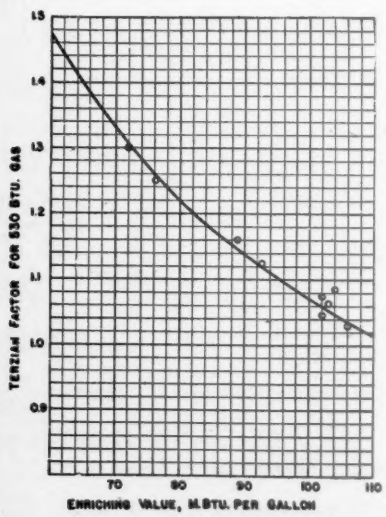
Where K_1 = Plant Constant
T = Tar Made gals/Mcf
F. C. & A. are shown above

The "Plant Constant" varies between .88 and .92, primarily due to the quality of the heavy oil used. Oils of high enrichment value give a low "Plant Constant," and oils of low enriching value give the higher figure. There is also a slight variation between different plants, even though the quality of the oil might be practically the same. This variation is due to certain plant characteristics such as the quality of fuel used, technique of operation, miscellaneous plant equipment, etc.

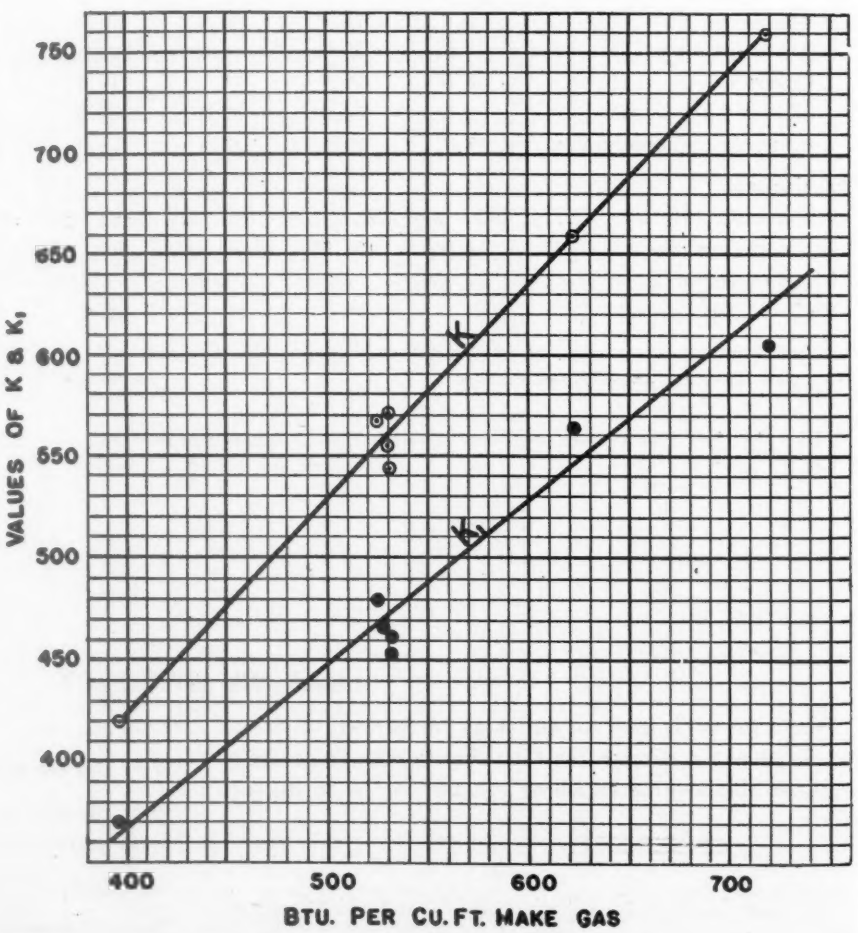
H. G. Terzian, 1936 AGA Production Conference.



Typical Relation of Terzian Factor to Gals. Tar Made per Mcf of 530 Btu Gas When Using Heavy Oils of Varying Enriching Qualities.



Typical Relation of Terzian Factor to Enriching Value of Heavy Oil when Making 530 Btu gas.



Relation of Make Gas Btu to K and K_1 Typical Values.

REFORMED GAS

The UGI cyclic catalytic reforming process—12′-0″ OD two shell standard unit.
Estimated operating data.

PART 1. PRODUCTION FOR LOW GRAVITY GAS SUBSTITUTE

Feed material for heating, process and enrichment	Natural Gas		Butane	
Quality of gas				
Btu of feed per cu. ft	1040		3200	
Specific gravity of feed	0.62		2.02	
Btu of reformed gas	280		287	
Specific gravity of reformed gas	0.48		0.41	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.52		0.54	
H_2 to inerts ratio-sendout gas	2.00		4.47	
Production				
Reformed gas—Mcf per day	11,400		8,300	
Sendout gas—Mcf per day	17,300		9,100	
Feed Materials Used Per MCF				
Reformed gas basis: total cu. ft., or gallons	337		3.55	
Sendout gas basis: total cu. ft., or gallons	564		5.97	
Gas Analyses—%	Reformed	Sendout	Reformed	Sendout
Illuminants	—	—	—	—
CO	13.5	8.9	16.0	14.6
H_2	54.3	35.7	64.0	58.5
CH_4	6.8	34.9	5.2	4.8
C_2H_6	0.3	0.2	—	—
Hi-paraffins	—	1.8	—	8.7
CO_2	8.1	5.8	7.0	6.4
O_2	0.3	0.7	0.4	0.3
N_2	16.7	12.0	7.4	6.7

PART II. PRODUCTION FOR MEDIUM GRAVITY GAS SUBSTITUTE

Feed material for heating, process and enrichment	Natural Gas		Butane	
Quality of Gas				
Btu of feed per cu. ft	1040		3200	
Specified gravity of feed	0.62		2.00	
Btu of reformed gas	239		259	
Specific gravity of reformed gas	0.60		0.48	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.61		0.63	
H_2 to inerts ratio-sendout gas	0.96		2.52	
Production				
Reformed gas—Mcf per day	15,300		9,300	
Sendout gas—Mcf per day	24.500		10,300	
Feed Materials Used Per MCF				
Reformed gas basis: total cu. ft., or gallons	279		3.20	
Sendout gas basis: total cu. ft., or gallons	550		5.92	
Gas Analyses—%	Reformed	Sendout	Reformed	Sendout
Illuminants	—	—	—	—
CO	11.2	7.0	14.4	13.0
H_2	40.3	25.1	57.6	52.1
CH_4	7.9	38.4	4.7	4.3
C_2H_6	0.4	0.2	—	—
Hi-paraffins	—	2.0	—	9.6
CO_2	6.4	4.5	7.7	7.0
O_2	0.4	1.0	0.4	0.3
N_2	33.4	21.8	15.2	13.7

PART III. PRODUCTION FOR HIGH GRAVITY GAS SUBSTITUTE

Feed material for heating, process and enrichment	Natural Gas		Butane	
Quality of Gas				
Btu of feed per cu. ft	1040		3200	
Specific gravity of feed	0.62		2.00	
Btu of reformed gas	186		236	
Specific gravity of reformed gas	0.69		0.51	
Btu of sendout gas	540		540	
Specific gravity of sendout gas	0.67		0.66	
H_2. to inerts raito-sendout gas	0.63		1.98	
Production				
Reformed gas—Mcf per day	19,000		9,800	
Sendout gas—Mcf per day	32,500		11,000	
Feed Materials Used Per MCF				
Reformed gas basis: total cu. ft., or gallons	239		3.02	
Sendout gas basis: total cu. ft., or galllns	565		5.94	
Gas Analyses—%	**Reformed**	**Sendout**	**Reformed**	**Sendout**
Illuminants	—	—	—	—
CO	8.8	5.1	13.6	12.2
H_2	32.8	19.2	54.4	48.7
CH_4	8.6	41.9	4.4	4.0
C_2H_6	0.4	0.2	—	—
Hi-paraffins	—	2.2	—	10.3
CO_2	6.4	4.3	8.1	7.3
O_2	0.4	0.9	0.3	0.3
N_2	42.6	26.2	19.2	17.2

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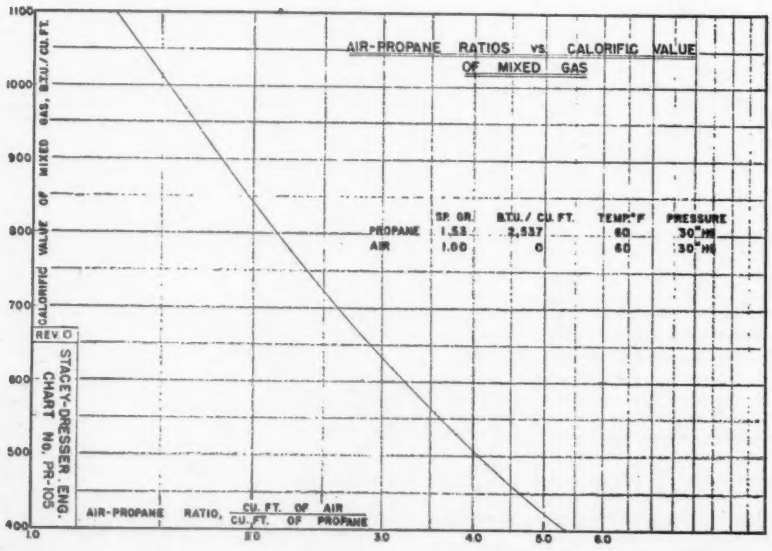
AIR-PROPANE RATIOS vs CALORIFIC VALUE



INTERCHANGEABILITY OF VARIOUS GASES

Interchangeability of gases is the use of a substitute gas for the gas usually distributed for domestic and industrial consumption without interfering with the operation of appliances used by the consumer.

The subject is complicated by many factors such as heating value, specific gravity, and composition of the various gases under consideration.

The present supply of natural gas has resulted in the distribution in many cities of gases of rather high heating values; in many cases, of straight natural gas having a heating value in excess of 1000 Btu per cubic foot.

The American Gas Association has found that none of the formulae developed earlier for the interchangeability of mixed gases of lower heating value were applicable to the interchangeability of the higher heating value gases. New equations, which would take into consideration all factors affecting interchangeability, have been developed.

Interchangeability Factors

The interchangeability of higher heating-value gases is considered from three distinct viewpoints — the tendency of high heating value supplemental gases to —

1. Lift
2. Flashback
3. Produce yellow tips

The index of lifting interchangeability, I_L, is the result obtained from calculation of the lifting interchangeability equation:

$$I_L = \frac{K_a}{\frac{t_a}{f_s}\,\frac{a_s}{a_a}\left(K_s\text{-log}\,\frac{f_a}{f_s}\right)}$$

Type of Natural Gas Distributed

The American Gas Association assumes that one of the three types of natural gas presented below would be the gas normally distributed.

		High btu nat. gas	High methane nat. gas	High inert nat. gas
Carbon dioxide	CO_2	0.5%	0.0%	0.5%
Methane	CH_4	83.0	94.5	71.4
Ethane	C_2H_6	16.0	0.0	14.0
Propane	C_3H_8	0.0	0.0	1.0
Nitrogen	N_2	0.5	5.5*	13.1
B.t.u. per cu. ft		1115	959	1000
Sp. gr.		0.64	0.56	0.69

* Inerts.

For any proposed adjustment, or substitute gas, all three indices must fall within certain numerical limits, which are shown in an accompanying table.

Interchangeability index	High-heating value nat. gas		High-methane nat. gas		High-inert nat. gas	
	Perferable	Objectionable	Perferable	Objectionable	Perferable	Objectionable
I_L	Under 1.0	Above 1.12	Under 1.0	Above 1.06	Under 1.0	Above 1.03
I_F	Under 1.18	Above 1.2	Under 1.18	Above 1.2	Under 1.18	Above 1.2
I_Y	Above 1.0	Under 0.7	Above 1.0	Under 0.8	Above 1.0	Under 0.9

AGA "Index C" Method

The American Gas Association "Index C" is a criteria developed for the interchangeability of gases with heating values below 700 Btu per cubic foot. If the supplemental gas has a "C" index in the range 0.85 to 1.15, it is considered that it could replace the base gas and maintain satisfactory appliance performance.

An empirical expression, I_F, denotes the tendency of burners to flashback as a result of interchanging a supplemental gas for natural gas.

$$I_F = \frac{K_s}{K_a}\,\frac{f_s}{f_a}\sqrt{\frac{h_s}{1000}}$$

Equation for I_Y takes into consideration changes in primary-air injection and yellow-tip limit resulting from substitution of one gas for another.

$$I_Y = \frac{f_s}{f_a}\,\frac{a_a}{a_s}\,\frac{Y_a}{Y_s}$$

Values for Equation Characters

In order to obtain values for the characters in these three equations, certain other equations must be employed, as follows:

Air theoretically required for complete combustion,

$$\text{per 100 Btu } a_a = \frac{100\,A_a}{h_a}$$

$$\text{Primary air factor } f_a = \frac{1000\sqrt{d_a}}{h_a}$$

$$\text{Lifting limit constant } K_a = \frac{F_a}{d_a}$$

$$\text{Yellow-tip limit } Y_a = \frac{100\,T_a}{A_a + 7E_a - 26.3\,O_{2a}}$$

The nomenclature for the above equations follows—

A = air theoretically required for complete combustion. cubic feet per foot of gas
a = air theoretically required for complete combustion. cubic feet per 100 Btu of gas
d = specific gravity (air = 1.0)
E = total inerts in gas mixture, decimal volume
F = lifting constant
f = primary-air factor
h = gross heating value, Btu per cubic foot
I_F = index of flashback interchangeability
I_L = index of lifting interchangeability
I_Y = index of yellow-tip interchangeability
K = lifting-limit constant
O_2 = oxygen in gas mixture, decimal volume
T = yellow-tip constant, cubic feet of air required to eliminate yellow tips per cubic foot of gas
Y = yellow-tip limit, per cent primary air
Subscript a = adjustment gas
Subscript s = substitute (or supplemental) gas.

The equation is—

$$C = \frac{h_s}{h_a}\,\frac{A_a}{A_s}\,\frac{d_a}{d_s} + (K_a - K_s)$$

where,

C = index of interchangeability
a = subscript denoting adjustment gas
s = subscript denoting substitute gas

h = gross heating value, Btu per cubic foot

A = air theoretically required for complete combustion, cubic feet per cubic foot of gas

d = specific gravity of gas (air = 1.0)

$K = \frac{hA}{5000\ E\ F}$, in which

E = the heat capacity of the theoretical products of combustion (from one cubic foot of gas) per degree F between 60 F and 1600 F, in Btu E is equal to 0.029 VCO_2 + 0.0023 VH_2O + 0.0189 VN_2 where V is the volume in cubic feet of each product (as indicated by the subscripts) formed by the combustion of one cubic foot of gas with the air theoretically required for complete combustion. The values 0.029, 0.023 and 0.0189 are, respectively, the heat capacities per degree F of CO_2, H_2O, and N_2, between 60 F and 1600 F in Btu per cubic foot.

F = Summation of the products of the mole fractions and some constant for each combustible constituent in the gas.

Disadvantages of "Index C" Equation

Several disadvantages are cited against the use of "Index C" in some cases.

1. It does not apply for mixtures in which the percentage of inerts exceeds the free-hydrogen content.

2. It is not generally applicable for mixtures involving adjustment and substitute gases of widely differing heating value or chemical composition unless the fraction of such radically differing gas in the substitute mixture does not exceed about 12 per cent. Thus the formula does not hold for such substitute mixtures as propane or butane and air, of natural gas inert mixtures, etc.

3. The formula does not usually apply in cases involving the use of large amounts of oil gases as substitutes for natural gas.

4. It is not fully applicable for gases of heating values higher than 800 Btu per cubic feet since the equation has no factors which predict the occurrence of yellow tips or lifting.

In 1946, the American Gas Association started a new series of tests on the interchangeability of gases of relatively low heating-value.

Knoy Formula

Several simple formulas have been proposed for use in determining the interchangeability of gases. The most well known is the Knoy formula, which is as follows:

$$C = \frac{H - 175}{\sqrt{G}}$$

C = a constant

H = heating value of gas, Btu per cubic foot

G = specific gravity of gas (air = 1)

175 = the heating value in Btu per cubic foot of the primary air-gas mixture which is assumed to be the proper adjustment for domestic burners.

The theory of this formula is that gases which have the same "C" factor are interchangeable. Actually the normal flexibility of most domestic-appliance burners allows some variation in the "C" factor. This deviation will not usually exceed 10 per cent up or down from the "C" factor of the adjustment gas. "C" factor for substitute gases which are above that of the adjustment gas indicate softer types of flames, while harder flames are indicated if the "C" factor is found to be below that for the adjustment gas.

It has been stated that the results obtained by the use of the Knoy formula may be misleading if the chemical composition of the substitute gas does not correspond to that of the adjustment gas, and as a rule, limit mixtures defined by means of AGA Index C are considered to be more reliable than those indicated by the Knoy formula.

New Test Burners Devised

Many test burners have been devised to assist in evaluating the interchangeability of gases by observation of flame characteristics. At the present time there is no available instrument which can be applied in all cases to evaluate the gas quality. In approaching a problem involving interchangeability of gas, it is desirable to make calculations first, using the interchangeability equations and then burn the prepared mixtures in appliances having burners characteristic of those used in the community to be certain that the substitute gases will actually burn satisfactorily.

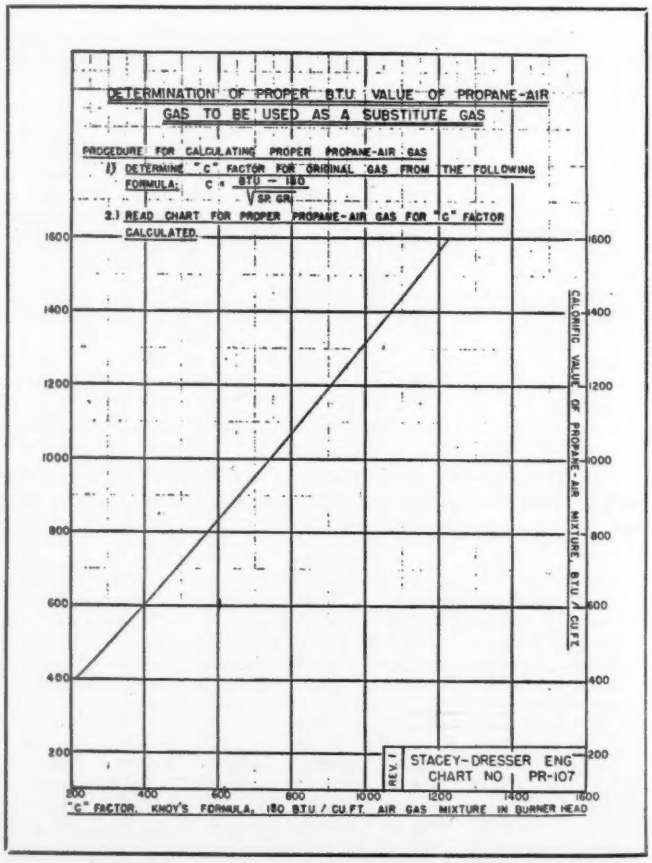
It is desirable that gas companies keep a control burner at the inlet and outlet of their gas-storage holders in order that they may, at all times, have a knowledge of the burning characteristics of the gas being produced and sent out.

Oil Gas Not Complete Replacement

It can be stated that high Btu oil gas, as now known, cannot be used as complete replacement for natural gas. However, some 30 to 60 per cent of these high Btu oil gases can be used in admixture with natural gas without excessive complaints from the consumers of the gas.

It must be pointed out that in some cases substitute gases appear to be entirely satisfactory from the standpoint of visual flame characteristics, but the products of combustion may contain dangerous quantities of carbon monoxide.

KNOY'S FORMULA FOR SUBSTITUTE GAS CALCULATIONS


DETERMINATION OF PROPER BTU VALUE OF PROPANE-AIR GAS TO BE USED AS A SUBSTITUTE GAS
PROCEDURE FOR CALCULATING PROPER PROPANE-AIR GAS
1) DETERMINE "C" FACTOR FOR ORIGINAL GAS FROM THE FOLLOWING FORMULA: C = BTU − 180 / √SP. GR.
2.) READ CHART FOR PROPER PROPANE-AIR GAS FOR "C" FACTOR CALCULATED
CALORIFIC VALUE OF PROPANE-AIR MIXTURE BTU / CU FT.
REV.1
STACEY-DRESSER ENG
CHART NO PR-107
"C" FACTOR, KNOY'S FORMULA, 180 BTU / CU FT. AIR GAS MIXTURE IN BURNER HEAD

GAS COMBUSTION CONSTANTS

No.	Gas	Formula	Lbs per cu. ft.	Cu. ft. per lb	Sp. gr. Air = 1.000	Heat of combustion: Btu per cu. ft. Gross	Heat of combustion: Btu per cu. ft. Net	Heat of combustion: Btu per lb Gross	Heat of combustion: Btu per lb Net	Cu. ft per cu. ft. of combustible: Required for combustion O_2	N_2	Air	Flue products CO_2	H_2O	N_2	Lbs. per lb. of combustible: Required for combustion O_2	N_2	Air	Flue products CO_2	H_2O	N_2
1	Carbon	C	.....	.....	.....	.....	.....	14,140†	14,140†	....	.....	....	.....	...	.....	2.667	8.873	11.540	3.667	.....	8.873
2	Hydrogen	H_2	0.005327	187.723	0.06959	323.5	275.1	61,100	51,643	0.5	1.882	2.382	...	1.0	1.882	7.939	26.414	34.353	.....	8.939	26.414
3	Oxygen	O_2	0.08461	11.819	1.1053	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
4	Nitrogen (atmos.)	N_2	0.07439*	13.443*	0.9718*	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
5	Carbon monoxide	CO	0.07404	13.506	0.9672	323.5**	323.5	4,369	4,369	0.5	1.882	2.382	1.0	...	1.882	0.571	1.900	2.471	1.571	.....	1.900
6	Carbon dioxide	CO_2	0.1170	8.548	1.5282	.....	.....	.....	.....	....	.....	.....	...	...	.....	....	.....	.....	.....	.....	.....
Paraffin series C_nH_{2n+2}																					
7	Methane	CH_4	0.04243	23.565	0.5543	1014.7‡	913.8	23,912	21,533	2.0	7.528	9.528	1.0	2.0	7.528	3.992	13.282	17.274	2.745	2.248	13.282
8	Ethane	C_2H_6	0.08029*	12.455*	1.04882*	1781	1631	22,215	20,312	3.5	13.175	16.675	2.0	3.0	13.175	3.728	12.404	16.132	2.929	1.799	12.404
9	Propane	C_3H_8	0.1196*	8.365*	1.5617*	2572	2371	21,564	19,834	5.0	18.821	23.821	3.0	4.0	18.821	3.631	12.081	15.712	2.996	1.635	12.081
10	Iso-butane	C_4H_{10}	0.1582*	6.321*	2.06654*	3251	2999	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
11	n-Butane	C_4H_{10}	0.1582*	6.321*	2.06654*	3353	3102	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
12	n-Pentane	C_5H_{12}	0.1904*	5.252*	2.4872*	3981	3679	20,908	19,322	8.0	30.114	38.114	5.0	6.0	30.114	3.551	11.815	15.366	3.052	1.499	11.815
13	n-Hexane	C_6H_{14}	0.2274*	4.398*	2.9704*	4667	4315	20,526	18,976	9.5	35.760	45.260	6.0	7.0	35.760	3.530	11.745	15.275	3.067	1.465	11.745
Olefin series C_nH_{2n}																					
14	Ethylene	C_2H_4	0.07456	13.412	0.9740	1631	1530	21,884	20,525	3.0	11.293	14.293	2.0	2.0	11.293	3.425	11.395	14.820	3.139	1.285	11.395
15	Propylene	C_3H_6	0.1110*	9.007*	1.4504*	2336	2185	21,042	19,683	4.5	16.939	21.439	3.0	3.0	16.939	3.425	11.395	14.820	3.139	1.285	11.395
16	Butylene	C_4H_8	0.1480*	6.756*	1.9336*	3135	2884	20,840	19,481	6.0	22.585	28.585	4.0	4.0	22.585	3.425	11.395	14.820	3.139	1.285	11.395
17	Acetylene	C_2H_2	0.06971	14.344	0.9107	1503	1453	21,572	20,840	2.5	9.411	11.911	2.0	1.0	9.411	3.075	10.231	13.306	3.383	0.692	10.231
Aromatic series C_nH_{2n-6}																					
18	Benzene	C_6H_6	0.2060*	4.852*	2.6920*	3741	3590	18,150	17,418	7.5	28.232	35.732	6.0	3.0	28.232	3.075	10.231	13.306	3.383	0.692	10.231
19	Toluene	C_7H_8	0.2431*	4.113*	3.1760*	4408	4206	18,129	17,301	9.0	33.878	32.878	7.0	4.0	33.878	3.128	10.407	13.535	3.346	0.783	10.407
20	Xylene	C_8H_{10}	.....	.....	.....	5155	.....	18,410	.....	10.5	39.524	50.024	8.0	5.0	39.524	3.168	10.540	13.708	3.318	0.849	10.540
21	Naphthalene	$C_{10}H_8$	.....	.....	.....	5859	.....	17,298		12.0	45.170	57.170	10.0	4.0	45.170	2.999	9.978	12.977	3.436	0.563	9.978
Miscellaneous gases																					
22	Ammonia	NH_3	0.04563*	21.914*	0.5961	433	.....	9,598	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
23	Hydrogen sulfide	H_2S	0.09109*	10.979*	1.1898*	672	.....	7,479	.....	1.5	5.646	7.146	SO_2= 1.0	1.0	5.646	1.408	4.685	6.093	SO_2= 1.880	0.529	4.685
24	Sulfur dioxide	SO_2	0.1733	5.770	2.264	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
25	Water vapor	H_2O	0.04758*	21.017*	0.6215*	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
26	Air	....	0.07655	13.063	1.0000	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....

NOTES:

All gas volumes corrected to 60° F. and 30" Hg dry.

* Densities calculated from values given in grams per liter at 0° C. and 760 mm. in the International Critical Tables for the known deviations from the gas laws. Where the coefficient of expansion was not available, the assumed value was taken as 0.0037 per ° C. Compare this with 0.003662 which is the coefficient for a perfect gas. Where no densities were available the volume of the mol was taken as 22.4115 liters. The asterisk (*) denotes that either the density or the coefficient of expansion has been assumed. The heats of combustion have been obtained by reviewing the experimental and critical data available. The 1929 A.G.A. Chemical Committee examined and approved the selection for the Gas Chemists Handbook. As far as possible the net heat of combustion per lb is the base figure from which all others were calculated. The data, given in mean Btu per lb (1/180th of the heat per lb of water from 32° F to 212° F.) have been compiled largely from Bureau of Standards publications, Bulletins of the University of Illinois Engineering Experimental Station, International Critical Tables, etc.

† Carbon — Roth and Naesser, Z. für Elektrochemie 31:461 (1925). White and black diamonds.

‡ Methane — Research Paper 260, Bureau of Standards (January 1931) corrected. C_8H_{10}, $C_{10}H_8$, H_2S and NH_3 from 1929 A.G.A. Gas Chemists Handbook.

For precise calculations with gases saturated with water vapor, 1.73% of the Btu value must be deducted to correct for the presence of water vapor.

Gross heating values are calculated from the net by allowing for the heat of vaporization of water at 60° F., amounting to 50.3 Btu per cu ft of water vapor or 1057.8 Btu per lb.

** Rossini in Bureau of Standards Research Paper 260 finds the heat of combustion of carbon monoxide to be 321.7 Btu per cu ft. Although not adopted for this edition, there is reason to believe that Rossini's value is the most accurate now available.

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PHYSICAL CONSTANTS OF HYDROCARBONS AND OTHER COMPOUNDS ASSOCIATED WITH NATURAL GAS

	Methane	Ethane	Propane	iso-butane	n-butane	iso-pentane	n-pentane	n-hexane	n-heptane	Carbon dioxide	Nitrogen	Oxygen	Ar	Hydrogen sulphide	Water
Atomic formula	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_4H_{10}	C_5H_{12}	C_5H_{12}	C_6H_{14}	C_7H_{16}	CO_2	N_2	O_2	.....	H_2S	H_2O
Molecular weight	16.042	30.068	44.094	58.120	58.120	72.146	72.146	86.172	100.198	44.01	28.016	32.000	28.966	34.076	18.016
Boiling point—760 mm. °F	—258.5	—128.2	—43.8	+10.0	+31.1	+82.3	+97.0	+155.7	+209.1	—109.3	—320.4	—297.4	.....	—76.5	212
°C	—161.4	—89.0	—42.1	—12.2	—0.5	+27.9	+36.1	+68.7	+98.4	—78.5	—195.8	—183.0	.....	—60.3	100
Melting point—760 mm. °F	—296.5	—297.8	—305.8	—229.0	—218.2	—257.1	—201.5	—139.9	—131.4	*	—345.6	—361.1	.....	—121.9	+32
°C	—182.5	—183.2	—187.7	—145.0	—139.0	—160.6	—129.7	—95.5	—90.8	*	—209.8	—218.4	.....	—85.5	0.0
Critical temperature °R	343.1	549.7	665.8	732.8	765.2	829.6	846.5	914.2	972.2	547.6	226.8	277.7	238.3	672.3	1165.0
°K	190.6	305.4	369.9	407.1	425.1	460.9	470.3	507.9	540.1	304.2	126.0	154.3	132.4	373.5	647.2
°F	—116.5	+90.1	206.2	273.2	305.6	370.0	387.0	454.6	512.6	88.0	—232.8	—181.8	—221.3	+212.7	+705.4
°C	—82.5	+32.3	96.8	134.0	152.0	187.8	197.2	234.8	267.0	31.1	—147.1	—118.8	—140.7	+100.4	+374.1
Critical pressure															
Atmospheres	45.8	48.2	42.0	35.2	37.5	32.8	33.0	29.5	27.0	73.0	33.5	49.7	37.2	88.9	218.2
Lb per sq. in. abs	673	708	617	517	551	482	485	434	397	1073	492	730	547	1306	3206.2
Critical volume															
Ml per gm. mol	99.0	148.0	195.0	249.0	258.0	307.6	310.9	367.2	427.0	95.6	90.1	74.4	93.4	.....	56.6
Cu. ft. per lb mol	1.586	2.371	3.123	3.990	4.130	4.930	4.98	5.88	6.84	1.532	1.443	1.192	1.496	.....	0.906
Critical density, lb. per gal	1.351	1.695	1.888	1.946	1.891	1.955	1.935	1.958	1.957	3.839	2.596	3.589	2.588	.....	2.658
Liquid density data															
Specific gravity 60°/60°F	0.3	0.4	0.509	0.564	0.584	0.625	0.631	0.664	0.688	.....	.....	.....	.....	0.79	1.000
°A.P.I. at 60°F	340.0	222.0	146.5	119.4	110.8	94.9	92.7	81.6	74.2	.....	.....	.....	.....	47.6	10.0
Density, lb. per gal. at 60°F (wt. in air)	2.5	3.3	4.23	4.69	4.86	5.20	5.25	5.53	5.73	.....	.....	.....	.....	6.58	8.327
Vapor density data (760 mm., 60°F															
Specific gravity (perfect gas) (air = 1.00)	0.554	1.038	1.522	2.006	2.006	2.491	2.491	2.975	3.459	1.519	0.967	1.105	1.000	1.176	0.622
Density (perfect gas)															
Cu. ft. per lb.**	23.66	12.62	8.61	6.53	6.53	5.26	5.26	4.40	3.79	8.62	13.54	11.86	13.10	11.14	21.06
Lb. per 1000 cu. ft.***	42.27	79.23	116.2	153.2	153.2	190.1	190.1	227.1	264.0	116.0	73.83	84.32	76.33	89.80	47.48
Cu. ft. vapor per gal. liquid (perfect gas)**	59.17	42.09	36.52	30.70	31.79	27.41	27.67	24.38	21.72	.....	.....	.....	.....	73.35	175.62
Gal. liquid per 1000 cu. ft. vap. (perfect gas)***	16.90	23.76	27.38	32.57	31.45	36.48	36.14	41.02	46.03	.....	.....	.....	.....	13.63	5.69
Ratio, gas volume per liquid volume (perfect gas)	442.6	314.8	273.2	229.7	237.8	205.0	207.0	182.4	162.5	.....	.....	.....	.....	548.7	1313.7
Deviation factor—(760 mm. 60°F.)	1.0020	1.008	1.016	1.030	1.032	1.045	1.048	1.066	1.087	1.0058	1.00030	1.00075	1.00039	1.011	1.0012
															13.25 mm.
100°F	1.0015	1.007	1.013	1.025	1.027	1.040	1.043	1.056	1.071	1.0047	1.00012	1.00052	1.00020	.....	1.0026
															49.1 mm.
Gross heat of combustion															
B.t.u. per lb. vapor	23.916	22.350	21.692	21.288	21.338	21.058	21.121	20.970	20.859	.....	.....	.....	.....	7.479	.....
B.t.u. per cu. ft. (perfect gas) 30-in.—60°F (dry)****	1013	1775	2526	3268	3276	4012	4025	4773	5521	.....	.....	.....	.....	673	.....
Specific heat, B.t.u. per lb. (760 mm., 60°F.)															
C_p	0.530	0.415	0.376	0.357	0.357	.....	0.347	0.339	0.335	0.199	0.248	0.218	0.241	0.254	0.458
C_v	0.405	0.346	0.324	0.312	0.312	0.309	0.309	0.305	0.302	0.153	0.176	0.155	0.171	0.192	0.343
C_p/C_v	1.309	1.198	1.161	1.144	1.144	1.121	1.121	1.113	1.109	1.304	1.404	1.401	1.410	1.32	1.335
C_p Liq	.....	.....	.....	.55 at 32	.55 at 32	.53	.64	.536	.522	.....	.....	.....	.....	.....	1.000
Heat of fusion B.t.u. per lb.—760 mm.	25.2	40.9	34.4	.....	32.4	30.4	49.9	65.0	59.6	81.5	11.0	5.9	.....	30.0	143.4
Heat of vaporization at boiling point. B.t.u. per lb.—760 mm	249	210	183	157	165	150	151	143	137	.....	.....	.....	.....	236	971
Vapor pressure at 100°F., lb. per sq. in. abs.	.....	.....	189.5	73.5	52.0	20.3	15.5	5.0	1.63	.....	.....	.....	.....	554.6	0.949
Octane No., Motor Method. A S T M D 357-37T	100+	100+	99.5	97.0	90.5	88.7	69.3	59.0	0.0	.....	.....	.....	.....	.....	.....

*Sublimes.
**To convert to a basis of 14.73 lb. per sq. in. or 30 in. Hg multiply by 0.99769.
***To convert to a basis of 14.73 lb. per sq. in. or 30 in. Hg multiply by 1.00232.
****To convert to a basis of water saturation at 60°F. multiply by 0.9825.

Note: Except where otherwise indicated, values are expressed on an "Actual" gas basis.

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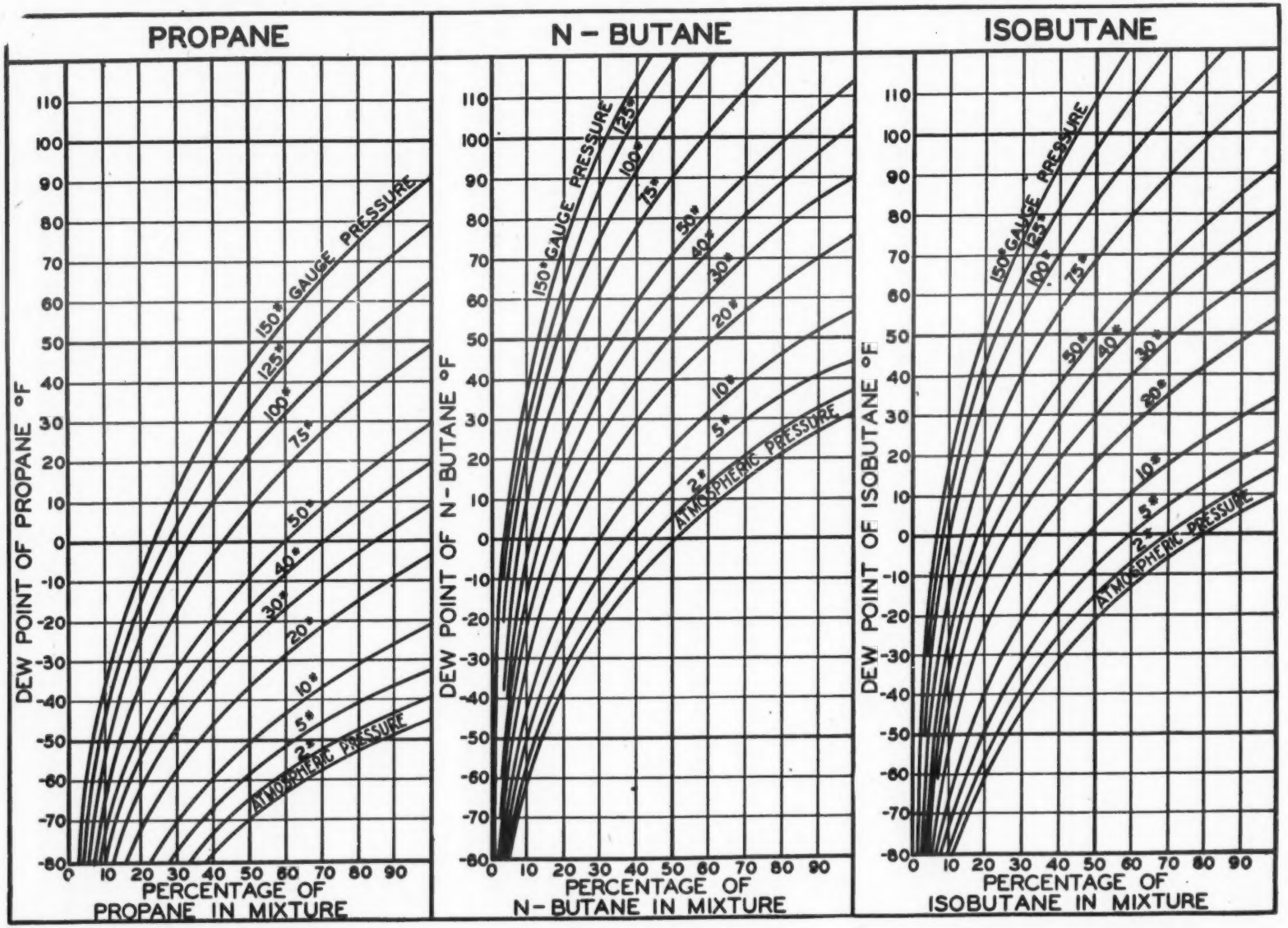
DEW POINTS OF PROPANE, NORMAL BUTANE AND ISOBUTANE, CARBURETTED WITH AIR



Copyright, page 38, 3rd edition Handbook Butane-Propane Gases.

AVERAGE PROPERTIES OF LIQUEFIED PETROLEUM GAS PRODUCTS

	Commercial propane	Industrial propane	Commercial butane
Vapor pressure lbs./sq. in. gauge			
at 70° F.	124	122	31
at 100° F.	192	190	59
at 105° F.	206	204	65
at 130° F.	286	282	97
Specific gravity of liquid (60°/60° F.)	0.509	0.511	0.582
Initial boiling point at 14.7 lbs./sq. in. abs., °F	—51	—51	15
Weight per gallon of liquid at 60° F., lbs.	4.24	4.26	4.84
Dew point at 14.7 lbs./sq. in. abs., °F	—46	—45	24
Specific heat of liquid, btu/lb./°F. at 60° F.	0.588	0.587	0.549
Cu. ft. of gas at 60° F., 30″ hg. per gallon of liquid at 60° F.	36.28	36.18	31.46
Specific volume of gas, cu. ft./lb. at 60° F., 30″ hg	8.55	8.50	6.50
Specific heat of gas, btu/lb./°F. at 60° F. (Cp)	0.404	0.401	0.382
Specific gravity of gas (Air = 1) at 60° F., 30″ hg	1.52	1.53	2.01
Ignition temperature in air, °F	920–1020	920–1020	900–1000
Maximum flame temperature in air, °F	3595	3600	3615
Per cent gas in air for maximum flame temperature, %	4.2–4.5	4.2–4.4	3.3–3.4
Maximum rate of flame propagation in 25 mm. tube:			
Cms. per second	84.9	85.9	87.1
Inches per second	33.4	33.8	34.3
Limits of inflammability in air, gas per cent in gas-air mixture:			
At lower limit, %	2.4	2.4	1.9
At maximum rate of flame propagation, %	4.7–5.0	4.7–4.9	3.7–3.9
At upper limit, %	9.6	9.6	8.6
Required for complete combustion:			
Cu. ft. O_2/cu. ft. gas	4.9	4.9	6.3
Cu. ft. air/cu. ft. gas	23.4	23.4	30.0
Lbs. O_2/lb. gas	3.60	3.59	3.54
Lbs. air/lb. gas	15.58	15.52	15.3
Products of complete combustion:			
Cu. ft. CO_2/cu. ft. gas	3.0	3.0	3.9
Cu. ft. H_2O/cu. ft. gas	3.8	3.8	4.6
Cu. ft. N_2/cu. ft. gas	18.5	18.5	23.7
Lbs. CO_2/lb. gas	3.0	3.0	3.1
Lbs. H_2O/lb. gas	1.6	1.5	1.5
Lbs. N_2/lb. gas	12.0	11.9	11.8
Ultimate CO_2, % by volume	13.9	13.9	14.1
Latent heat of vaporization at boiling point:			
Btu per pound	185	184	167
Btu per gallon	785	784	808
Total heating values (after vaporization):			
Btu per cubic foot	2522	2537	3261
Btu per pound	21560	21570	21180
Btu per gallon	91500	91800	102600

Phillips Petroleum Company, with permission.

SPECIFICATIONS AND TEST METHODS NGAA LIQUEFIED PETROLEUM GAS

The following specifications and test methods for liquefied petroleum gases were adopted as Tentative Standards by the Natural Gasoline Association of America, effective September1, 1940.

Commercial Propane

Definition. Commercial Propane shall be a hydrocarbon product composed predominantly of propane and/or propylene and shall be free from harmful quantities of deleterious substances.

Composition. The composition of Commercial Propane shall be at least 95 per cent propane and/or propylene by liquid volume as determined by the combined results of the Vapor Pressure and Mercury Freezing Tests.

Mercury Freezing Test. The residue as determined by means of the Mercury Freezing Test shall not be more than two per cent by volume.

Vapor Pressure. The vapor pressure at 105° F., as determined by the Liquefied Petroleum Gas Vapor Pressure Method shall not be in excess of 225 pounds per square inch gage pressure.

Sulphur Content. The product shall be free of hydrogen sulphide and shall not contain mercaptans, or sulphur compounds, of corrosive nature. The unstenched product shall not contain total sulphur in excess of fifteen (15) grams per hundred (100) cubic feet of vapor as determined by the test for Total Sulphur in Liquefied Petroleum Gases.

Water Content. The product shall satisfactorily pass the standard Cobalt Bromide Test.

Odorization. A sufficient quantity of an odorizing agent of such character as to indicate positively the presence of gas down to concentrations in air of not over one-fifth the lower limit of flammability by a distinctive odor shall be added by the manufacturer; provided, however, that odorization is not required if harmful in the use or further processing of the liquefied petroleum gas, or if odorization will serve no useful purpose as a warning agent in such use or further processing.

Commercial Butane

Definition. Commercial Butane shall be a hydrocarbon product composed predominantly of butane and/or butylenes and shall be free from harmful quantities of deleterious substances.

Vapor Pressure. The vapor pressure at 105° F. as determined by the Liquefied Petroleum Gas Vapor Pressure Method, shall not be in excess of 75 pounds per square inch by gage pressure.

95 Per Cent Boiling Point. The quantity evaporated at a temperature of 34° F., corrected to a barometric pressure of 740 mm. Hg., shall be 95% or more by volume, as determined by the Open Cylinder Weathering Test.

Sulphur Content. *Same as for Commercial Propane.*

Water Content. The product shall be free of mechanically entrained water.

Odorization. *Same as for Commercial Propane.*

Butane-Propane Mixtures

Definition. Butane-Propane mixtures shall be hydrocarbon products composed predominantly of mixtures of butanes and/or butylenes with propane and/or propylene and shall be free from harmful quantities of deleterious substances.

Vapor Pressure. *Same as for Commercial Propane.*

Product Designation. Butane-Propane mixtures shall be designated by the vapor pressure at 100° F. in pounds per square inch gage. To comply with the designation the vapor pressure of mixtures shall be within +0 lbs. —5 lbs. of the vapor pressure specified. For example, a product specified as 95 lbs. LP-G shall have a vapor pressure of at least 90 lbs. but not exceeding 95 lbs.

95 Per Cent Boiling Point. *Same as for Commercial Butane.*

Sulphur Content. *Same as for Commercial Propane.*

Water Content. *Same as for Commercial Butane.*

Odorization. *Same as for Commercial Propane.*

VAPORIZATION OF LIQUID IN PROPANE TANKS

Many times the question arises, especially on peak shaving installations using propane: Is it necessary to turn on the vaporizers?

For comparatively short-time peak shaving it is possible to obtain sufficient vapor from the storage tank itself without passing liquid propane through the vaporizer.

It is a well-known fact that the vapor pressure of a gas bears a direct relationship to the temperature and that the latent heat of vaporization is the amount of heat required to convert a liquid to a gas (also known as boiling point) at given pressure and temperature conditions; and further:

"The rate of heat transfer has been set at 2 Btu per hour per degrees temperature differential per sq. ft. of tank area in contact with the liquid."

Knowing these basic gas laws, we can evolve a formula to determine the amount of liquid propane vaporized in a standard storage tank in one hour.

$$\frac{2\ \text{Btu} \times (T_1 - T_2) \times \text{wetted area in sq ft}}{\text{LH per gal}} = \text{Gal/hr}$$

T_1 = Outside air temperature in degrees F

T_2 = Ultimate temperature in degrees F of propane liquid at minimum required pressure condition

LH: per gal = Latent Heat of vaporization (in Btu's) to vaporize one gallon of propane at T_2

As an example, let us assume that a 30,000 (wc) tank is half full of propane (wetted area = 1014 sq. ft.) and the outside air temperature is 80 F and the required vapor pressure can be as low as 10 psi gauge. How many gallons per hour is available due to the vaporization of liquid in storage tank?

Referring to standard table of thermodynamic properties of propane; temperature at 10 psi ga is —20 F; and the latent heat of vaporization is 750 Btu per gal.

From the above formula —

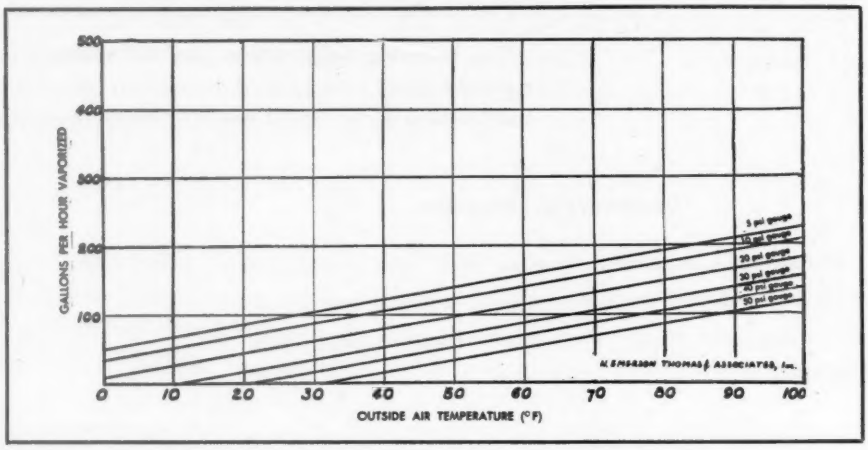
$$\frac{2\ \text{Btu} \times (80°\text{F} - (20°\text{F}) \times 1014\ \text{sq ft}}{750\ \text{Btu per gal}} = 271\ \text{gal}$$

With the above conditions, we therefore can vaporize 271 gallons per hour without recourse to a vaporizer.

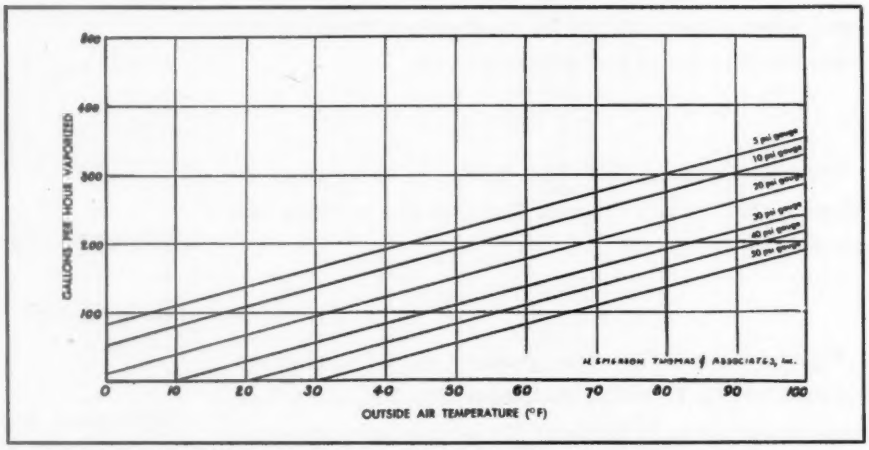
If this draw is maintained over a long period of time on a humid day, the surface of the tank in contact with the liquid will become frosted due to the refrigeration action of the liquid vaporized and the effective temperature differential will be substantially reduced. But in this discussion we are considering only comparatively short usages so as to obtain maximum vaporization.

Using the basic formula, graphs have been plotted which give available gallons per hour vaporized at various outside temperatures and pressure requirements of vapor and at varying filling heights in a 30,000 gallon (wc) tank containing commercial grade propane.

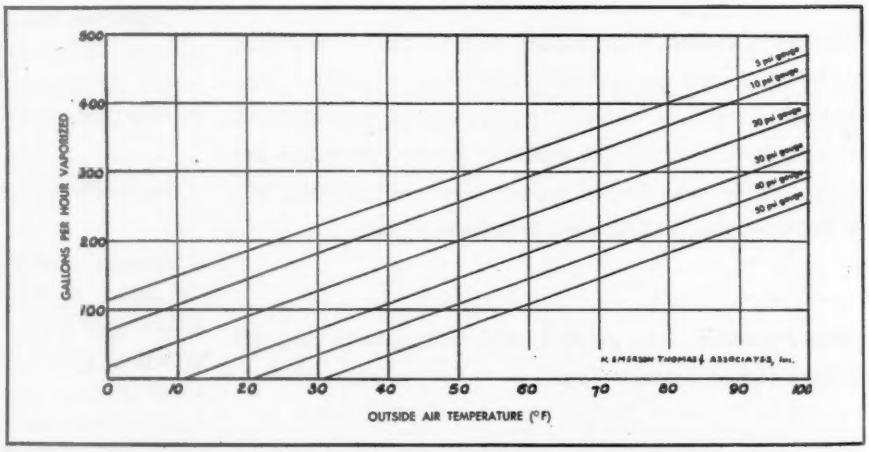
Referring to the graphs it is possible to decide when the vaporizer equipment will be required to obtain the necessary gas load.



Vaporization in 30,000 gallon tank, ¼ full—662 sq ft.



Vaporization in 30,000 gallon tank, ½ full—1014 sq ft.



Vaporization in 30,000 gallon tank, ¾ full—1365 sq ft.

Art E. Wastie, chief engineer, H. Emerson Thomas and Associates, Westfield, N. J.

CALCULATING EXPLOSIVE LIMITS OF GAS MIXTURES IN AIR

Coward and his co-workers have arranged the Le Chatelier formula in the following form for calculating the limits in air of any mixture of combustible gases to which it is applicable:

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \text{—}}$$

Where P_1, P_2 and P_3 are the proportions of each combustible gas present in the original mixture, free from air and inert gases so that

$$P_1 + P_2 + P_3 + \text{—} = 100$$

and N_1, N_2, N_3 are the limits in air for each gas separately, no inest gases being psesent.

EXPLOSIVE LIMITS OF SELECTED INDUSTRIAL GASES IN AIR

Kind of Gas	Heating value B.t.u./ Cu. Ft.	Composition—% by Volume								Explosive Limits	
		CO_1	Ill.	O_2	CO	H_2	CH_4	C_1H_6	N_2	Lower	Upper
Blue	310	6.2	0.0	0.3	39.2	49.0	2.3		3.0	6.9	69.5
	308	1.9	0.0	0.3	45.0	47.5	1.2		4.1	6.1	67.4
Carburetted	509	4.6	7.3	0.3	36.0	37.0	9.6		5.2	6.4	37.7
Blue	538	3.9	8.2	0.7	32.4	33.7	13.1		8.0	6.8	37.3
	541	5.7	10.2	0.7	26.1	28.3	8.1	1.9	19.0	7.3	31.6
Coal	549	2.4	2.7	0.4	9.7	44.9	28.9		11.0	5.6	30.8
		1.6	3.1	1.2	8.5	50.3	26.0		9.3	5.8	29.0
Coke oven	631	1.9	3.9	0.4	6.3	54.4	31.5		1.6	5.0	28.4
	540	2.5	3.4	0.8	11.1	47.9	24.2		10.1	5.3	30.0
	547	2.3	4.0	1.5	7.8	46.8	24.6	1.0	12.0	6.0	28.4
"Mixed"	540	2.5	3.2	0.5	10.5	47.0	25.8		10.5	5.6	31.7
	540	3.8	5.7	1.3	22.4	38.5	18.1		10.2	6.3	34.0
	540	3.1	8.1	0.8	21.5	33.7	15.0	1.0	16.8	6.8	30.8
Producer	136	6.2	0.0	0.0	27.3	12.4	0.7		53.4	20.7	73.7
	118	5.4	0.0	0.0	26.6	9.3	0.4		58.3	18.6	*
Natural										4.8	13.5

S. S. Tomkins.

GAS IGNITION TEMPERATURES AND EXPLOSIVE LIMITS IN AIR

Gas or vapor	Ignition temperature °F	Explosive limits	
		Lower limit per cent by volume	Upper limit per cent by volume
Carbon monoxide	1204	12.5	74.0
Hydrogen	1085	4.1	74.2
Methane	999	5.3	14.0
Ethane	950	3.2	12.5
Propane	871	2.37	9.5
n-Butane	806	1.6	8.5
iso-Butane	1010	1.9	8.5
Pentane	588	1.45	7.5
Hexane	500	1.2	6.9
Ethylene	842	2.75	28.6
Propylene	927	2.0	11.1
Benzene	1000	1.5	8.0
Toluene	1026	1.27	7.0
Xylene	900	1.0	5.3
Acetylene	581*	2.5	80.0
Naphthalene	1038	0.9	
Ammonia	1204	16.0	25.0
Hydrogen sulphide	500	4.3	46.0

National Fire Protection Association excerpt from Bureau of Mines Report of Investigations 3567.

SAFE END-POINTS IN PURGING OPERATIONS INVOLVING VARIOUS COMBUSTIBLE AND INERT GASES

Combustible gas or vapor	Inert gas	Safe end point—per cent by volume	
		Purging from air to gas maximum permissible oxygen content of atmosphere in container	Purging from gas to air maximum permissible combustible gas content of atmosphere in container
Mixed gas	Nitrogen	8.6	11.0
Carburetted blue gas	Nitrogen	8.0	11.8
Coal gas	Nitrogen	9.0	10.0
Benzol vapor	Nitrogen	11.6	4.8
Hydrogen	Carbon dioxide	8.1	8.9
	Nitrogen	5.1	5.7
Carbon monoxide	Carbon dioxide	9.8	31.5
	Nitrogen	6.6	19.5
Methane	Carbon dioxide	15.7	22.6
	Nitrogen	12.8	14.0
Ethane	Carbon dioxide	14.0	11.7
	Nitrogen	11.4	7.2
Propane	Carbon dioxide	14.9	10.8
	Nitrogen	11.9	6.4
Butane	Carbon dioxide	15.0	9.2
	Nitrogen	12.4	5.6
Ethylene	Carbon dioxide	12.2	10.0
	Nitrogen	10.3	6.3

S. S. Tomkins.

RAPID SURVEY METHOD OF GAS REQUIREMENTS AND COSTS

In many of its phases, the selling of gas heat is very much like other specialty selling where the cost of the item or of the service to be furnished depends on the particular conditions surrounding the individual prospect.

The estimate of annual operating cost for one prospect may figure only $50.00, whereas that for another would be $500.00. When the one in the $500.00 class first makes inquiry about gas heat, his interest may be based on thinking in terms of $50.00. Likewise, the one who is in the $50.00 class may not have exhibited any interest, because he was thinking in terms of $500.00.

A method, therefore, whereby the salesman in the field can figure the estimate with reasonable accuracy and in just a few minutes time, is of great assistance in qualifying prospects. Such a method can be made sufficiently accurate to justify the salesman in attempting to close the order on the basis of the rapid survey method. If successful, then before the installation is made, his engineering department, if it so desires, can make a more elaborate survey and estimate. This can be done as if it is merely a part of the usual installation routine, so that the customer's confidence in the salesman is not affected in any way. Should this detailed survey show any glaring discrepancies, the matter can be taken up with the customer in advance of installation, so that no one will be unfavorably affected.

To show how such a rapid survey can be developed, the starting point is the formula used by heating engineers in figuring the seasonal operating cost to take care of any given area of wall, ceiling or floor.

FORMULA

$$\frac{\text{(Heat loss in Btu per Hour)}}{\text{Area} \times \text{Heat Transfer Coefficient} \times \text{Temp. Rise} \times \text{Hrs. Heated} \times \text{Degree Days} \times \text{Gas Rate in Cts. Per M Cu Ft}}{\text{Temperature Rise} \times \text{Btu Heat Content} \times \text{Efficiency} \times 1000 \times 100} = \text{Season's Operating Cost in Dollars for that Area}$$

While there are many factors in the long formula, examination will show that for any certain type of construction practically all of them are constant for any given territory. The coefficient of any certain material is always the same — the temperature rise is nearly always figured at 70 degrees — the temperature differential between basement and hour interior 20 degrees — and between interior and attic 35 degrees — the number of hours per day is always 24 — the number of degree days for any given territory is regarded as a constant — the gas rate and the Btu content are constant for a territory. While the efficiency factor may vary slightly with different types of equipment, an average efficiency of 75 per cent can be used for reasonably accurate results. This means that all of the factors in that long formula can be condensed for any territory into one single factor for each type of construction. Then it is simply a case of multiplying the given area by one factor instead of working out the entire formula shown above.

Another point of simplification is to measure the house as a whole rather than to measure the individual rooms. It is simple for the salesman to compute the volume by measuring the width, height, and depth of the house. Naturally, if the prospect states that certain rooms have not been heating satisfactorily with the old furnace equipment, then individual rooms should be measured and duct work or radiation checked. Just as in the case of figuring the heat loss through the walls, ceiling, or floor, the volume can be multiplied by a single constant to determine the seasonal operating cost for offsetting loss by infiltration.

With the above thought in mind, a single factor, which for purposes of clarity in explaining is called factor "F", has been worked out for the most commonly encountered types of construction. To convert this factor "F" into the correct constant for any territory, it is only necessary to multiply it by a certain multiplier, designated as "M," with "M" being determined as follows:

$$M = \frac{\text{Local Degree Days} \times \text{Average Local Heating Rate in Cents per M/Cu Ft}}{\text{Btu Content of Local Gas}}$$

or

$$M = \frac{\text{Local Degree Days} \times \text{Rate per Therm in Cents}}{100{,}000}$$

The following table gives the factor "F" for the most unusual types of building constructions. Figure local multiplier, "M," as outlined above, multiply M by F and then it is possible to fill in this table with the local constant which will be used in figuring the seasonal operating cost to offset the heat loss through any given area of wall, ceiling, or floor.

Type of Material	Factor "F"	Multiplier "M"	Final constant
Single glass	0.000352	.....	.....
Double glass	0.000143	.....	.....
Walls:			
8″ Brick, sheathing, stud, L&P	0.000085	.....	.....
Stucco, wood, and plaster	0.000099	.....	.....
Stone, tile, furred, L&P	0.000077	.....	.....
Clapboards, studding, L&P	0.000080	.....	.....
Floors:			
Wood floor. No. ceiling below	0.000042	.....	.....
Double floor. L&P below	0.000022	.....	.....
Ceilings:			
Plaster board and plaster	0.000098	.....	.....
Rigid insulation and plaster	0.000056	.....	.....
Roofs:			
Tile or slate on wood	0.000179	.....	.....
Shingles, sheathing, stud, L&P	0.000102	.....	.....
Volume:			
To offset air infiltration:			
One air change per hour	0.0000058	.....	.....
One and one-half air changes	0.0000087	.....	.....
Two air changes per hour	0.0000116	.....	.....

NOTE: For any wall construction not listed above which may be found to be common in the locality, the factor "F" may be obtained by:
Coefficient of Transmission × 0.00032 = F

After the above final constants for the territory have been worked out, it is recommended that they be printed on a survey card arranged along the lines of the one reproduced here. The reverse side of the card can carry the usual general information as to the prospect's name and address, date of survey, and the like.

With permission, from Surface Combustion Corp.

SUGGESTED FORM FOR RAPID SURVEY METHOD

Area sq. ft.	Material	Local factor	Operating cost per season
....	Glass: Single	....	$.....
....	Glass: Double	....	.....
....	Walls (net): 8″ brick	....	.....
....	Stucco, tile and plaster	....	.....
....	Stone, tile, furred, L&P	....	.....
....	Clapboards, studding, L&P	....	.....
....	.....	....	.....
....	Floors: Wood floor, no ceil. below	....	.....
....	Double floor: L&P below joists	....	.....
....	.....	....	.....
....	Roofs: Tile or slate on wood	....	.....
....	Shingles, sheathing, studding, L&P	....	.....
....	.....	....	.....
Cu. ft.	Volume		
....	Infiltration: 1 air change per hr	....	.....
....	1½ air changes per hr	....	.....
....	2 air changes per hr	....	.....
	Total operating cost per season	....	$.....

If Btu heat loss per hour is desired, use formula $= \frac{218{,}750 \times \text{Season's Cost}}{M}$

HEAT DELIVERY OF SPACE HEATING EQUIPMENT

STEAM: 1 sq ft cast iron radiation = 240 Btu/hr (2 Lb steam 70 F room temp)

HOT WATER: 1 sq ft cast iron radiation = 150 Btu/hr 70 F room temp

FORCED HOT WATER: 1 sq ft cast iron radiation = 200 Btu/hr (70 F room temp)

GRAVITY WARM AIR: 1 sq in. of basement duct (175 F register temp)

= 110 Btu/hr on first floor

= 166 Btu/hr on second floor

= 200 Btu/hr on third floor

FORCED WARM AIR: *The following formula gives the heat delivered at the register of a forced warm air heating system.*

$$H = A \times V \times 60 \times W \times S \times (t_d - t_r)$$

Symbols:

H = Heat delivered in Btu per hour.

A = Net area of discharge register in sq ft.

V = Velocity of air leaving register in ft per minute.

W = Weight of air at temperature t_d in pounds per cubic foot.

S = Specific heat of air in Btu per pound per degree F at temperature t_d.

t_d = Temperature in degrees F of air leaving register.

t_r = Temperature in degrees F of space being heated.

With permission, "Surface Combustion Industrial Heating Handbook."

EXAMPLE

CONDITIONS

Assume the following conditions for the computation of the seasonal operating cost in a home:

Two and one-half story residence

Walls: 8″ brick, lath and plaster inside over sheathing

Ceilings second floor: Plaster board and plaster

No flooring in attic

Floors: Frame construction, single thickness

Single glass windows

Air changes per hour: 1

Gross wall area:
- First floor, 1300 sq ft
- Second floor, 1150 sq ft

Glass area:
- Windows and doors
- First floor, 190 sq ft
- Second floor, 130 sq ft

Area second floor ceiling: 1010 sq ft

Area first floor: 1010 sq ft

Cubical contents:
- First floor, 9100 cu ft
- Second floor, 8700 cu ft
- Degree days 6000
- Gas rate 40c/M cu ft
- Btu content 530

PRELIMINARY

$$M = \frac{6000 \times 40}{530} = 453$$

Final constant for glass area	=	.000352	× 453 =	.159
Final constant for wall area	=	.000085	× 453 =	.0385
Final constant for floor area	=	.000042	× 453 =	.019
Final constant for ceiling area	=	.000098	× 453 =	.044
Final constant for infiltration	=	.0000058	× 453 =	.0026

SOLUTION

320 square feet glass area	×	.159	=	$ 50.88
2,130 square feet wall area	×	.0385	=	82.00
1,010 square feet floor area	×	.019	=	19.19
1,010 square feet ceiling area	×	.044	=	44.44
17,800 cubic feet infiltration	×	.0026	=	46.28
				$242.79

LOWEST RECORDED TEMPERATURES AND ANNUAL DEGREE DAYS FOR CITIES OF UNITED STATES AND CANADA[1]

DEGREE DAY is a term used to express the intensity of the heating season. It is the difference between 65° F. and the daily mean temperature. The sum of these differences for every day of the heating season is the total degree days for the year. Experience has shown that the gas heating season starts when the monthly mean temperature is 65° F., and that gas consumption for house heating is proportional to the drop in temperature below 65° F.

City	Min. temp.	Degree-Days
Alabama		
Anniston	3	2813
Gadsden	—13	3006
Montgomery	— 5	1886
Tuscaloosa	— 7	2529
Arizona		
Flagstaff	—25	7145
Tucson	6	1845
Arkansas		
Bergman	—17	3956
Little Rock	—12	2811
Texarkana	— 7	2216
California		
Bakersfield	13	2047
Fresno	17	2375
Los Angeles	28	1504
Sacramento	19	2654
San Diego	25	1645
San Francisco	29	3264
Colorado		
Buena Vista	—37	8849
Colorado Springs	—27	6553
Denver	—29	5873
Pueblo	27	5514
Connecticut		
Hartford	—18	6037
New Haven	—14	5895
Delaware		
Wilmington	—12	4788
District of Columbia		
Washington	—15	4626
Florida		
Monticello	16	1129
Tampa	9	296
Georgia		
Atlanta	— 8	2891
Augusta	3	2161
Macon	— 4	2203
Savannah	8	1490
Idaho		
Boise	—28	4558
Springfield	—28	7477
Illinois		
Chicago	—23	6315
Joliet	—25	6535
Springfield	—24	5370
Indiana		
Evansville	—16	4164
Fort Wayne	—24	5916
Indianapolis	—25	5297
South Bend	—20	6076
Iowa		
Davenport	—27	6287
Des Moines	—30	6373
Dubuque	—32	6788
Sioux City	—35	7023
Kansas		
Emporia	—23	4792
Topeka	—25	5301
Wichita	—22	4877
Kentucky		
Lexington	—20	4616
Louisville	—20	4180
Louisiana		
Baton Rouge	2	1349
New Orleans	7	1023
Shreveport	— 5	1938
Maine		
Bar Harbor	—21	7643
Portland	—21	7012
Maryland		
Baltimore	— 7	4333
Frederick	No. fig.	5928
Massachusetts		
Boston	—14	6145
Fitchburg	—17	6732
Williamstown	—26	7221
Michigan		
Ann Arbor	—21	6865
Cadillac	—36	7967
Detroit	—28	6494
Grand Rapids	—24	6534
Kalamazoo	—25	6625
Lansing	—26	7112
Sault Ste. Marie	—37	9281
Minnesota		
Duluth	—41	9480
Minneapolis	—33	7851
Rochester	—42	8123
Mississippi		
Columbia	9	1740
Corinth	— 8	3411
Tupelo	— 7	2780
Vicksburg	— 1	1809
Missouri		
Grand City	—29	5659
Jefferson City	—25	4874
Kansas City	—22	5202
St. Louis	—22	4585
Montana		
Billings	—49	7115
Butte	—33	8271
Helena	—42	8054
Nebraska		
Dumas	—31	7203
Omaha	—32	6128
Nevada		
Las Vegas	8	2842
Reno	—19	5891
New Hampshire		
Concord	—35	6852
Hanover	—37	8063
Keene	—28	7457
New Jersey		
Atlantic City	— 7	5175
Dover	—21	5970
Newark	—13	5387
New Brunswick	—15	5405
Sussex	—24	6134
Trenton	—13	4934
New Mexico		
Albuquerque	—10	4303
Santa Fe	—13	6063
New York		
Albany	—24	6889
Buffalo	—14	6821
Ithaca	—22	6719
New York City	—13	5348

[1]*From AGA "Househeating" and U. S. Weather Bureau.*

City	Min. temp.	Degree-Days
Ogdensburg	—43	7490
Plattsburg	—25	7894
Rochester	—14	6733
Saranac Lake	—39	8673
Syracuse	—22	6592
North Carolina		
Asheville	No. fig.	4263
Greensboro	— 3	3527
Wilmington	5	2302
North Dakota		
Bismarck	—45	8498
Hannah	—54	10714
Ohio		
Akron	—20	6069
Cincinnati	—17	4702
Cleveland	—17	6154
Columbus	—20	5323
Oklahoma		
Hugo	— 3	2648
Oklahoma City	—17	3613
Tulsa	—15	3560
Oregon		
Portland	— 2	4468
Wallowa	—38	7360
Pennsylvania		
Erie	—16	5866
Gettysburg	—20	5580
Philadelphia	— 6	4855
Pittsburgh	—20	5235
Reading	—14	5388
Scranton	—15	6129
Rhode Island		
Providence	—12	6014
South Carolina		
Charleston	7	1769
Columbia	— 2	2364
Spartanburg	— 4	3257
South Dakota		
Aberdeen	—46	8709
Jefferson	—48	8419
Tennessee		
Knoxville	—16	3670
Memphis	— 9	2950
Nashville	—13	3578
Texas		
Austin	— 1	1578
Dallas	—10	2455
Eagle Pass	— 7	871
Galveston	8	1016
San Antonio	4	1202
Utah		
Provo	—23	6184
Salt Lake City	—20	5553
Vermont		
Burlington	—28	7620
Northfield	—41	8420
Virginia		
Fredericksburg	—21	4243
Roanoke	—12	4068
Richmond	— 3	3725
Washington		
Seattle	3	4868
Spokane	—30	6353
Walla Walla	—17	4809
West Virginia		
Charleston	—17	3786
Huntington	—24	4734
Wheeling	No. fig.	5249
Wisconsin		
Green Bay	—36	7823
Milwaukee	—25	7372
Superior	—35	9750
Wyoming		
Casper	—30	6979
Cheyenne	—38	7462
Canada		
Vancouver, B. C.		5976
Winnipeg, Man.		11166
Toronto, Ont.		7732
Montreal, Que.		8705
Quebec, Que.		8628

AVERAGE RELATIVE HUMIDITY

	Station	Length of record (yrs.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Ala.	Mobile	48	74	73	73	71	71	72	68	76	74	70	71	77	72
	Montgomery	46	70	67	64	62	62	64	70	72	67	64	66	71	67
Ariz.	Phoenix	42	48	47	39	31	25	23	35	41	38	38	43	50	38
Ark.	Little Rock	46	69	67	63	62	66	66	66	67	67	65	66	70	66
Calif.	Fresno	50	76	69	62	52	44	36	31	33	39	49	61	76	52
	Los Angeles	49	56	61	61	64	68	68	67	67	64	61	51	54	62
	San Francisco	44	75	72	70	70	72	74	79	80	74	70	69	74	73
Colo.	Denver	48	52	52	49	49	49	44	44	45	44	46	48	52	48
D. C.	Washington	36	66	63	61	59	65	69	71	70	71	71	66	68	67
Fla.	Jacksonville	54	74	72	69	67	69	72	74	75	77	75	74	75	73
	Miami	30	73	72	70	69	71	74	73	73	75	74	71	73	73
Ga.	Atlanta	38	72	69	66	63	64	67	73	74	71	67	67	72	69
Idaho	Boise	[1]41	73	67	55	49	46	43	34	33	41	51	62	73	52
Ill.	Chicago	27	75	73	70	66	66	67	65	68	70	67	70	76	69
Ind.	Indianapolis	54	75	71	67	61	60	61	59	63	64	64	69	74	66
Iowa	Des Moines	50	79	77	72	65	65	68	66	70	72	70	73	78	71
Kans.	Wichita	54	70	65	59	58	63	61	57	57	60	60	64	70	62
Ky.	Louisville	48	72	69	65	61	61	62	62	64	65	63	67	71	65
La.	New Orleans	47	75	73	71	70	69	70	74	74	73	70	72	75	72
Maine	Eastport	48	74	74	73	74	76	79	82	81	80	77	75	75	77
Mass.	Boston	31	68	66	65	65	67	67	68	71	71	68	70	68	68
Mich.	Detroit	42	84	85	74	68	66	66	62	64	68	71	76	81	71
	Sault Ste. Marie	33	84	82	78	70	68	70	73	75	79	79	82	84	77
Minn.	Minneapolis	42	79	76	68	60	58	63	60	62	66	66	72	78	64
Miss.	Vicksburg	72	74	70	68	70	72	74	78	79	76	73	72	74	73
Mo.	Kansas City	38	72	69	65	63	65	66	61	64	66	63	66	72	66
	St. Louis	46	71	68	64	61	62	62	59	62	64	62	65	71	64
Mont.	Helena	57	68	66	58	53	52	50	43	44	51	57	64	68	56
	Miles City	[2]50	75	73	68	57	53	54	47	48	54	61	70	75	61
Nebr.	North Platte	48	70	67	61	57	59	61	58	58	60	58	63	70	62
	Omaha	38	75	74	68	62	64	66	63	66	66	63	69	75	67
Nev.	Winnemucca	38	76	70	58	49	60	40	30	29	37	49	62	74	52
N. J.	Atlantic City	57	74	73	73	72	75	77	78	78	76	73	72	73	75
N. Mex.	Albuquerque	21	60	52	44	39	36	33	45	49	50	49	51	61	47
N. Y.	Albany	38	75	74	70	66	65	69	70	72	76	74	74	75	72
	New York	47	66	64	63	61	63	65	69	70	70	67	68	67	65
	Rochester	46	74	74	69	63	61	63	62	64	68	69	72	74	68
N. C.	Asheville	40	71	68	65	61	63	68	72	75	72	68	66	70	68
	Raleigh	57	73	71	69	66	68	72	76	79	78	74	71	74	72
N. Dak.	Bismarck	56	76	75	69	59	57	61	57	56	60	63	72	76	66
Ohio	Cleveland	52	59	58	59	58	61	64	65	66	66	66	58	59	61
Okla.	Oklahoma City	36	71	68	62	63	68	68	62	62	64	66	66	71	66
Oreg.	Portland	48	81	77	71	65	64	63	60	62	66	74	80	81	70
Pa.	Harrisburg	56	68	65	62	56	58	63	63	65	66	66	64	65	64
	Pittsburgh	49	73	73	67	62	61	64	63	65	66	67	70	77	67
S. C.	Charleston	52	70	65	63	65	65	78	78	78	77	77	72	78	72
S. Dak.	Huron	56	78	77	69	61	58	62	58	59	60	62	70	77	66
Tenn.	Nashville	38	75	70	66	62	66	67	68	71	70	67	69	73	69
Tex.	Amarillo	52	60	57	50	49	56	54	52	54	57	58	57	61	55
	El Paso	55	44	38	30	25	25	28	41	45	44	42	43	48	38
	Fort Worth	34	67	66	59	62	64	61	58	58	61	63	64	69	63
	Houston	33	75	74	72	73	74	73	74	73	74	70	71	75	73
Utah	Salt Lake City[3]	13	80	74	62	54	47	45	38	39	43	56	71	77	57
Vt.	Burlington	38	80	81	77	72	70	73	75	77	81	79	79	81	77
Va.	Norfolk	8	72	69	68	67	71	74	77	77	77	74	71	72	72
	Richmond	47	72	67	64	61	64	67	70	72	72	69	67	71	68
Wash.	Seattle	39	81	80	73	68	67	66	66	69	72	79	82	82	73
	Spokane	54	82	75	62	52	49	47	38	40	50	62	78	83	60
W. Va.	Parkersburg	37	76	74	68	64	67	72	71	74	74	72	72	76	72
Wis.	Madison	37	81	79	73	65	64	67	64	67	70	70	76	82	71
Wyo.	Cheyenne	41	55	58	57	58	56	53	48	49	49	50	51	55	53

"Statistical Abstract of the United States." U. S. Department of Commerce.

REQUIRED WATER HEATER CAPACITIES

Capacity of Hot Water Equipment Needed to Supply Fixtures in Various Types of Buildings

Gallons Per Maximum Hour

Fixture	Apt. house	Club	Gymnasium	Hospital	Hotel	Indst. plant	Laundry	Office bldg.	Public bath	Private house	School	Y.W.C.A. Y.M.C.A.
Wash basin (private)	3	3	3	3	3	3	3	3	3	3	3	3
Wash basin (public)	5	8	10	10	10	15	10	15	15	..	15	15
Bath tub	15	15	30	15	15	30	..	..	45	15	..	30
Dish washer	15	30	..	30	30	30	..	..	..	15	15	..
Foot basin	3	3	..	3	3	..	..	..	..	3	..	10
Kitchen sink	10	20	..	20	20	20	..	..	..	10	10	20
Laundry tub (stationary)	25	35	..	35	35	..	45	..	45	25	..	45
Laundry tub (revolving)	75	75	..	100	150	..	100	..	100	75	..	100
Pantry sink	10	20	..	20	20	..	10	..	..	10	20	20
Shower	100	200	300	100	100	300	..	..	300	100	300	200
Slop sink	20	20	..	20	30	20	..	20	20	15	20	20
Dish washer	250 gallons per hour for each 500 people											
% of total water likely be drawn in one hour	20	30	60	40	30	70	80	15	80	30	25	30

Buenger, A. Journ. A.S.H. & V. E.

APPROXIMATE FUEL CONSUMPTIONS FOR WATER HEATING

Fuel	Btu in Unit as Sold	Typical Overall efficiency	Fuel Consumption per Month, (based on a daily draw of 50 gallons, or 1500 gallons of hot water monthly)
Gas:			
Manufactured	530 Btu per cubic foot	68–61%	2690–2940 cubic feet
Natural	1100 Btu per cubic foot	68–61%	1350–1475 cubic feet
Mixed	Varies with mixture	68–61%	Consult local compnay
Electricity	3412 Btu per Kwh	86–74%	340–390 Kwh
Oil:			
Summer	138,000 Btu per gallon	20– 8%	36–87 gallons
Winter	138,000 Btu per gallon	45–20%	16–34 gallons
Kerosene	136,000 Btu per gallon	40–25%	18–28 gallons
Coal:			
Indirect heater	12,000 Btu per pound	27–24%	305–350 pounds
Furnace coil	12,000 Btu per pound	28–24%	302–348 pounds
Pot stove	12,000 Btu per pound	17–13%	504–656 pounds

CAPACITY OF PIPE

Cubic feet of gas per hour 0.3″ pressure drop; 0.6 spec. gr.

Length of pipe (ft.)	Diameter of pipe inches ½	¾	1	1¼	1½	2	3	4
15	76	172	345	750	1,220	2,480	6,500	13,880
30	52	120	241	535	850	1,780	4,700	9,700
45	43	99	199	435	700	1,475	3,900	7,900
60	38	86	173	380	610	1,290	3,450	6,800
75		77	155	345	545	1,120	3,000	6,000
90		70	141	310	490	1,000	2,700	5,500
105		65	131	285	450	920	2,450	5,100
120			120	270	420	860	2,300	4,800
150			109	242	380	780	2,090	4,350
180			100	225	350	720	1,950	4,000
210			92	205	320	660	1,780	3,700
240				190	300	620	1,680	3,490
270				178	285	580	1,580	3,250
300				170	270	545	1,490	3,000

MULTIPLIERS

To convert gas flow at 0.6 spec. grav. to flow at another gravity

Specific gravity	Multiplier
2.0	0.547
1.5	0.633
1.4	0.654
1.3	0.680
1.2	0.707
1.1	0.740
1.0	0.775
0.9	0.817
0.8	0.866
0.7	0.926
0.6	1.000
0.5	1.095
0.4	1.225

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COMPARISON OF GAS AND ELECTRICITY IN COMMERCIAL COOKING

The opportunity was provided for making a study by the replacement of the commercial cooking equipment in Alfonso's Restaurant in Washington, D. C., where a careful record was kept of operating conditions, meals served and utility consumptions. As a result, replacement factors for gas and electricity in a typical commercial cooking establishment were obtained, that were based on long periods of practical operation under identical conditions.

RESULTS OF STUDY

New Gas Equipment Versus New Electric Equipment

Electricity used for cooking during the months, October, 1946 — through July, 1947: 116,190 kwh.

Gas used for cooking during the ten months from October, 1947, through July, 1948, totaled 5,434 therms.

Electric cooking equipment having a rating of 82.8 kw added 45.15 kw to the maximum demand, which amounted to 54 per cent of the connected load.

When electricity was used for cooking, average monthly consumption:

Cooking only	11,619 kwh
Lights and other uses	3,601 kwh
Total for all purposes	15,220 kwh

Maximum electric billing demand (Connected cooking load of kitchen 82.8 kw)

Cooking only	45.15 kw
Lights and other uses	14.75 kw
Total demand	59.90 kw

When gas was used for cooking:

Average monthly consumption of gas for cooking . . . . . 543 therms

Average monthly consumption of electricity for lights and other uses 3601 kwh

Maximum electric billing demand for lights and other uses . . . . . 14.75 kw

The data obtained in this study furnish authentic replacement factors indicating the relative consumptions of gas and electricity for commercial kitchen operation, typified by Alfonso's Restaurant:

Heating value of gas Btu	1000 cu. ft. are equivalent to this this many kwh	1 kwh is equivalent to this many cubic feet
525	112.1	8.90
540	115.2	8.65
850	181.9	5.50
1,000	213.7	4.68
1,100	235.1	4.25
2,500	534.0	1.87

1.371 Btu of gas are equivalent to 1 Btu of electricity
.0468 therms of gas are equivalent to 1 kwh of electricity
1 therm of gas is equivalent to 21.4 kwh of electricity

These factors are based upon actual amounts of gas and electricity used for cooking purposes without correction for the difference in the number of meals served, although this results in a slight benefit to electricity. Actually, 1 per cent more meals were cooked with gas.

"A Comparison of Gas and Electric Usage for Commercial Cooking," American Gas Association.

RELATIVE COST OF GAS AND ELECTRIC COOKING

The conclusions reached by the American Gas Association in their Bulletin No. 6 are as follows:

Item	Scope of Test	Energy Ratio
1.	Top burner performance	1.532
2.	Oven performance	2,624
3.	Week's menu (upper income)	2.077
4.	Week's menu (limited income)	1.799
5.	Foor for Infant	1.754

Accepting an energy ratio of 1.9 the following formula will facilitate calculators:

$$\frac{1.9 \times 3413}{\text{Btu of Gas}} = \text{cu ft of gas equivalent to 1 Kwh.}$$

in which if 525 Btu. per cu ft of gas is being burned, then by substitution

$$\frac{1.9 \times 3413}{525} = 12.35 \text{ cu ft of gas equivalent to 1 Kwh.}$$

With the foregoing as a basis, the tabulation below represents the "break even" gas cost per Mcf for electricity at different costs per Kwh, fuel cost only being considered on a 1.9 energy ratio.

Cost per Kwh., cents	Break-even cost per Mcf. Btu of gas per cu. ft.					
	500	525	550	750	1000	1100
1.0	$0.77	$0.81	$0.85	$1.16	$1.54	$1.70
1.5	1.16	1.21	1.37	1.73	2.31	2.54
2.0	1.54	1.62	1.70	2.32	3.08	3.40
2.5	1.93	2.02	2.12	2.89	3.86	4.24
3.0	2.32	2.42	2.54	3.46	4.62	5.08
3.5	2.70	2.83	2.97	4.05	5.40	5.94
4.0	3.08	3.24	3.40	4.64	6.16	6.80
5.0	3.86	4.04	4.24	5.78	7.72	8.48

COMMERCIAL COOKING AND BAKING REQUIREMENTS

In Btu per meal served

Class	Electricity	Gas	Oil	Coal
Clubs, first class	4,270	8,280	11,450	15,750
Hotels, first class	3,415	6,620	9,200	12,650
Cafeteria, first class	2,140	4,080	5,670	7,800
Institutions	1,708	3,340	4,630	6,360
Hospitals	1,280	2,490	3,450	4,750
College mess halls	482	935	1,300	1,785

Steam tables, coffee urns, hot water, dish washing, etc., adds 30 to 50 per cent to the above figures.

With permission, "Surface Combustion Industrial Heating Handbook."

INDUSTRIAL HEATING OPERATIONS

Materials, operations and approximate temperature range

Material	Operation	Approx. Temp. Range (°F)
Aluminum alloy	Aging	250–460
Aluminum alloy	Annealing	450–775
Aluminum alloy	Forging	750–900
Aluminum alloy	Heat treating	310–1000
Aluminum	Melting	1200–1400
Aluminum alloy	Die casting	1250–1400
Antimony	Melting point	1166
Asphalt	Melting	350–450
Babbitt	Melting	600–800
Brass	Annealing	600–900
Brass	Extruding	1400–1450
Brass	Forging	1200–1400
Brass, yellow	Melting	1705
Brass, red	Melting	1830
Bread	Baking	300–500
Brick	Burning	1800–2600
Brick, refractory	Burning	2500–3000
Bronze, 5% alum.	Melting	1940
Bronze, man.	Melting	1645
Bronze, phos.	Melting	1920
Bronze, tobin	Melting	1625
Cadmium	Melting point	610
Cake (food)	Baking	300–350
Calcium	Melting point	1562
Calender rolls	Heating	300
Candy	Cooking	225–300
Cast iron	Annealing	1600–1700
Cast iron	Malleablizing	1650–1800
Cast iron	Vitreous enameling	1200–1300
Cement	Kiln firing	2800–3000
China	Glazing	1500–1900
Clay, refrac.	Burning	2200–2600
Cobalt	Melting point	2714
Coffee	Roasting	600–800
Coke	By-product oven	1830–2730
Cookies	Baking	375–450
Copper	Annealing	800–1200
Copper	Refining	2100–2600
Copper	Melting	2100–2300
Copper	Smelting	2100–2600
Cores, sand	Baking	250–550
Cupronickel, 15%	Melting	2150
Cupronickel, 30%	Melting	2240
Electrotype	Melting	740
Enamel	Baking	250–450
Everdur 1010	Melting	1865
Frit	Smelting	2000–24000
Glass	Annealing	800–1200
Glass	Melting, pot furnace	2300–2500
Glass, bottle	Melting, tank furnace	2500–2900
Glass, flat	Melting, tank furnace	2500–3000
Gold	Melting	1950–2150
Iron	Blast furnace tap.	2500–2800
Iron, malleable	Melting	2400–3100
Iron, malleable	Annealing	1500–1700
Japan	Baking	300–450
Lacquer	Drving	150–200
Lead	Melting	620–750
Lead	Blast furnace	1650–2200
Lead	Refining	1800–2000
Magnesium	Aging	350–400
Magnesium	Heat treating	730–760
Magnesium	Melting	1250–1300
Magnesium	Superheating	1450–1650
Meat	Smoking	100–150
Mercury	Melting point	–38
Molds, foundry	Drying	400–750
Molybdenum	Melting point	4757
Monel metal	Annealing	1100–1480
Monel metal	Melting	2800
Muntz metal	Melting	1660
Nickel	Annealing	1100–1480
Nickel	Melting	2650
Palladium	Melting point	2829
Phosphorous, yellow	Melting point	111
Pie	Baking	500
Pigment	Calcining	1600

INDUSTRIAL HEATING OPERATIONS

Materials, operations and approximate temperature range
(Continued)

Material	Operation	Approx. Temp. Range (°F)
Platinum	Melting	3224
Porcelain	Burning	2600
Potassium	Melting point	145
Potato chips	Frying	350–400
Primer	Baking	300–400
Silicon	Melting point	2606
Silver	Melting	1750–1900
Sodium	Melting point	208
Solder	Melting	400–600
STEEL		
Steel, sheet	Blue annealing	1400–1600
Sheet	Box annealing	1500–1700
Sheet	Bright annealing	1250–1350
Sheet	Job mill heating	2000–2100
Sheet	Mill heating	1800–2100
Sheet	Open annealing	1500–1700
Sheet	Tin plating	650
Sheet	Vitreous enameling	1400–1650
Sheet, tin plate	Box annealing	1200–1650
Sheet, tin plate	Hot mill heating	1800–2000
Sheet, tin plate	Lithographing	300
Steel	Bessemer converter	2800–3000
Steel	Calorizing	1700
Steel	Carburizing	1500–1700
Steel	Case hardening	1600–1700
Steel	Cyaniding	1400–1800
Steel	Drawing forgings	850
Steel	Drop forging	2200–2400
Steel	Forging	1700–2150
Steel	Form-bending	1600–1800
Steel	Galvanizing	800–900
Steel	Heat treating	700–1800
Steel	Lead hardening	1400–1800
Steel	Melting, open hearth	2800–3100
Steel	Melting, electric furn.	2400–3200
Steel	Normalizing	1650–1900
Steel	Rolling	2300
Steel	Soaking pits	1900–2100
Steel	Upsetting	2000–2300
Steel	Welding	2400–2800

Material	Operation	Approx. Temp. Range (°F)
Steel bars	Heating	1900–2200
Steel billets	Heating	2250
Steel blooms	Heating	2250
Steel bolts	Heading	2200–2300
Steel castings	Annealing	1300–1600
Steel flanging	Heating	1800–2100
Steel ingots	Heating	2000–2200
Steel nails	Blueing	650
Steel pipe	Butt welding	2400–2600
Steel rails	Hot bloom reheating	1900–2050
Steel rivets	Heating	2000–2200
Steel rod	Mill heating	1900–2100
Steel shape	Heating	1900–2200
Steel slabs	Heating	2000–2200
Steel spikes	Heating	2000–2200
Steel springs	Annealing	1500–1650
Steel wire	Annealing	1200–1400
Steel wire	Pot annealing	1650
Steel wire	Baking	300–350
Steel, alloy tool	Hardening	1425–2150
Steel, alloy tool	Preheating	1200–1500
Steel, alloy tool	Tempering	325–1250
Steel, carbon	Hardening	1360–1550
Steel, carbon tool	Hardening	1450–1500
Steel, carbon	Tempering	300–1100
Steel, carbon tool	Tempering	300–550
Steel, hi-carbon	Annealing	1400–1500
Steel, hi-speed	Hardening	2250–2375
Steel, hi-speed	Preheating	1450–1600
Steel, hi-speed	Tempering	1000–1150
Steel, S.A.E.	Annealing	1400–1650
Tin	Melting	500–650
Type metal	Stereotyping	525–650
Type metal	Linotyping	550–650
Type metal	Electrotyping	650–750
Varnish	Cooking	520–600
Vitreous enamel	Firing	1400–1700
Zinc	Melting	800–900
Zinc alloy	Die dasting	850

"Hauck Industrial Combustion Data." Copyright 1953, Hauck Manufacturing Co.

COMBUSTION CHARACTERISTICS OF TYPICAL GASES

(Caculated on dry basis)

Kind of Gas	Constituents of Gas—Per Cent by Volume										Specific gravity	Btu per cu. ft.		Cu. Ft. of air per cu. ft. of gas	Products of combustion per volume of gas			Ultimate % CO_2
	CO_2	O_2	N_2	CO	H_2	Ill.	CH_4	C_2H_6	C_3H_8	C_4H_{10}		gross	net		CO_2	H_2O vapor	N_2	
Natural gas, Kettleman Hills, California—Stripped casinghead	..	..	..	..	..	..	85.4	8.6	5.1	0.9	.67	1183	1071	11.06	1.215	2.215	8.742	12.2
Natural gas, Long Beach, Los Angeles basin, California—stripped casinghead	0.5	.	..	..	..	..	86.8	7.2	4.3	1.2	.66	1161	1051	10.87	1.194	2.184	8.587	12.2
Natural gas, San Joaquin Valley, California—dry	0.1	..	1.2	..	..	..	98.7	..	..	..	.56	1000	902	9.40	.987	1.974	7.442	11.7
Natural gas, Gulf Coast area, Texas—Stripped	0.2	1.0	7.7	..	..	..	88.8	2.3	..	..	.61	941	849	8.80	.934	1.845	7.027	11.7
Natural gas—Texas Panhandle	0.1	0.1	7.7	..	..	..	82.2	6.1	2.4	1.4	.67	1052	952	9.85	1.076	1.997	7.882	12.0
Natural gas, West Virginia	0.8	..	1.1	..	..	..	75.0	23.1	..	..	.69	1174	1064	11.00	1.212	2.193	8.700	12.2
Natural gas—casinghead, Unstripped	1.0	..	1.1	..	..	..	66.6	31.3	..	..	.74	1236	1122	11.56	1.292	2.271	9.148	12.4
Natural gas—sour	..	..	..	H_2S	6.4	..	58.7	16.5	9.9	8.5	.91	1478	1348	13.79	1.589 SO_2.064	2.589	11.094	12.5
Coal gas (Horizontal Retort)	2.1	0.4	3.5	8.7	50.5	3.8	28.2	2.8	..	..	.43	612	549	5.28	.568	1.240	4.241	11.8
Coal gas (Horizontal Retort)	2.8	0.6	8.8	7.4	41.6	4.5	34.3	..	..	..	.49	606	545	5.27	.589	1.206	4.299	12.1
Coal gas (Vertical retort)	3.0	0.6	3.1	7.0	50.4	3.1	32.8	..	..	..	.41	587	525	5.06	.527	1.231	4.060	11.5
By-product coke oven gas	2.1	0.4	6.1	5.0	52.9	3.2	30.3	..	..	..	.40	565	505	4.86	.476	1.209	3.935	10.8
By-product coke oven gas	1.5	0.3	5.0	5.0	58.0	2.8	27.4	..	..	..	.36	544	484	4.64	.429	1.192	3.741	10.3
By-product coke oven gas	2.5	0.8	10.1	11.1	47.6	3.4	24.5	..	..	..	.47	513	461	4.35	.490	1.044	3.571	12.1
By-product coke oven gas	2.3	1.5	12.0	7.8	46.8	4.0	24.6	1.0	..	..	.48	532	478	4.51	.495	1.082	3.723	11.7
Carburetted water gas—Gas oil enrichment	3.3	0.7	3.8	33.4	38.1	10.7	10.0	..	..	..	.65	563	520	4.53	.799	.827	3.822	17.3
Carburetted water gas—Heavy oil with blow-run	4.6	0.6	16.7	24.1	32.5	10.3	9.0	2.2	..	..	.71	535	494	4.38	.740	.808	3.825	16.2
Carburetted water gas—Heavy oil with blow-run	5.8	0.6	11.5	25.0	34.4	9.2	13.5	..	..	..	.68	527	485	4.32	.737	.826	3.717	16.5
Carburetted water gas—Heavy oil with reforming and blow run	5.3	0.6	12.8	21.9	36.5	8.3	14.6	..	..	..	.65	515	472	4.24	.684	.848	3.648	15.8
Carburetted water gas—High heating value	1.1	0.6	3.8	13.7	30.5	15.8	33.1	1.4	..	..	.63	820	753	7.23	.986	1.404	5.754	14.6
Uncarburetted water gas	6.2	0.3	3.0	39.2	49.0	..	2.3	..	..	..	.55	309	281	2.31	.477	.536	1.852	20.5
Butane air gas	..	17.6	66.4	..	..	..	..	..	..	16.0	1.17	544	503	4.11	.640	.800	3.915	14.1
Propane air gas	..	16.6	62.4	..	..	..	..	..	21.0	..	1.12	544	501	4.21	.630	.840	3.952	13.7
Propane air gas	..	14.5	54.6	..	..	..	..	..	30.9	..	1.17	801	737	6.67	.927	.1236	5.815	13.7
Refinery oil gas—liquid Phase cracking (cross Still)	..	0.2	0.6	1.2	6.1	5.0	4.4	72.5	..	..	1.00	1665	1530	15.35	1.926	2.654	12.208	13.6
Refinery oil gas—vapor Phase cracking (gyro Still)	0.1	1.0	..	1.2	13.1	39.6	23.3	21.7	..	..	.88	1465	1350	13.20	1.789	2.119	10.626	14.4
Reformed refinery oil gas	4.0	0.6	4.8	18.2	52.1	3.6	16.7	..	..	..	.47	476	429	3.93	.504	.938	3.189	13.6
Reformed natural gas—Water gas generator	1.9	0.2	6.5	17.1	39.1	2.3	32.9	..	..	..	.50	566	511	4.91	.593	1.102	3.964	13.0
Oil gas	3.0	0.6	4.4	9.7	50.2	4.0	28.1	..	..	..	.44	567	509	4.85	.536	1.156	3.912	12.1
Producer gas—anthracite	6.6	..	49.0	25.1	18.7	0.3	0.3	..	..	..	.84	151	141	1.13	.330	.200	1.386	19.2
Producer gas—Bituminous	2.5	0.3	55.3	27.0	12.0	0.4	2.5	..	..	..	.87	160	151	1.23	.333	.179	1.529	17.9
Blast furnace gas	9.4	..	61.8	27.8	1.0	..	..	..	..	..	1.01	93	92	.69	.372	.010	1.160	24.3

AVERAGE ECONOMY OF INDUSTRIAL FURNACES WITH GOOD OPERATION

Process	Millions of Btu per net ton	Efficiency per cent
FERROUS PRODUCTS		
Ingot heating, soaking pits	1.0	24
Billet heating for forming Batch—		
In-and-out type	3.5	20
Continuous non-recuperative	2.2	32
Bar annealing, pit or car type	2.6	17
Wire annealing—hood type, coils	2.7	16
strand in lead	2.2	19
strand, open fired	1.2	32
stainless, catenary strand	2.7	24
Caustic pickle, stainless wire coils	0.7	26
Wire temper, open heat, lead quench	4.0	19
Wire patenting, strands	2.5	20
Wire galvanizing, strands	0.8	30
Wire tinning, strands	0.4	35
Wire baking, coils, continuous	0.5	32
Nail galvanizing, retort	0.3	—
Nail blueing, continuous retort	0.4	—
Tube reheating, sizing mill	1.5	18
Tube annealing—Continuous, bright	1.2	35
Batch, car type	1.5	28
Tube normalizing, continuous roll-down	1.7	33
Tube galvanizing	1.2	20
Skelp heating, butt weld—batch	3.8	20
continuous	3.0	25
Slab heating, continuous recuperative	1.6	43
Sheet bar heating—batch	2.2	22
continuous	1.7	29
Sheet and strip annealing, hood type—		
Carbon steels	1.2	27
Alloy steels	2.0	19
Strip annealing, continuous coils	1.6	24
Strip, bright annealing, strands	1.2	32
Sheet normalizing, continuous, wasters	3.5	17
Sheet galvanizing	1.0	24
Nickle stainless sheet anneal, strands	3.0	21
Caustic pickle stainless strip, continuous	0.3	—
Nickle stainless sheet anneal, batch	4.5	16
Enamelling—cast iron, three coats, batch	4.0	21
Flat ware, continuous	2.6	18
Hardening, continuous conveyor type	2.5	20
Drawing, continuous conveyor type	1.5	21
Carburizing, boxes, continuous	4.5	12
Carburizing, gas, continuous	3.0	18
Annealing steel castings	3.7	13
NON-FERROUS PRODUCTS		
Copper and brass—		
Billet or cake heating, continuous	0.8	30
Wire annealing—coils, continuous	1.5	16
strands, bright	1.1	22
Sheet and strip anneal, continuous, pans	0.8	30
Cartridge case anneal, continuous	1.3	19
Aluminum—		
Billet heating	1.4	32

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FUEL CONSUMPTION OF TYPICAL FURNACES

	Btu/1000 Brick
Brick, kilns:	
Hoffman continuous kiln	3,920,000-4,760,000
Ruebon kiln	5,880,000-9,240,000
Grates and trough	4,760,000-6,300,000
Staffordshire kiln	4,760,000-6,300,000
Buhrer continuous tunnel	3,220,000-3,900,000
	Btu/Ton
Metal melting:	
Iron and steel:	
Puddling	14,000,000
Open-hearth	3,000,000-6,500,000
Air furnace for malleable castings	8,600,000
Copper, reverberatory	4,200,000
Tin, smelting	19,200,000
Rolling-mill furnaces:	
Busheling	5,600,000-7,000,000
Billet heating	2,240,000-2,520,000
Billet heating (4 by 4)	2,800,000-4,200,000
Continuous furnace (cold billets)	1,500,000-2,250,000
Continuous-bloom furnace	1,400,000-2,100,000
Reheating cold blooms	1,960,000-2,800,000
Soaking pits (hot to cold ingots)	250,000-2,000,000
Tire furnaces	4,500,000
Wheel furnaces	8,400,000
Sheet annealing	2,800,000
Tin-plate mill	2,500,000
Rivet making:	
Rivet-making furnaces	1,260,000
Forging:	
Drop forging or bolt heating	6,000,000-7,000,000
Ingot forging	4,000,000-5,000,000
Ingot forging (regeneration furnace)	3,500,000-4,000,000
Brass annealing	1,500,000-2,000,000
Heat-treatment:	
Casehardening	4,500,000-5,000,000
Quenching	2,000,000-3,000,000
Tempering	1,500,000-2,000,000

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PHYSICAL CLASSIFICATION OF REFRACTORIES

Refractory	PCE	High temp strength	Spalling resistance	Iron oxide slagging resistance[a]	Remarks
Silica	31–32	Excellent	Sensitive below 600°C	Fair	Widely used for sprung arches because of high-temperature strength
Fireclay	19–34	Fair	Fair depends on manufacture	Poor	General purpose material. Inexpensive
High-alumina	Above 38	Properties improve with increasing Al_2O_3			Used for more severe conditions than fireclay will withstand
Mullite	38	Excellent	Good	Good	
Magnesite	38 and above	Good	Sensitive. Depends somewhat upon manufacture	Superior	Expensive. Used in matallurgical furnaces. High heat capacity
Forsterite	Over 32	Excellent	Good	Excellent	Indicated where both high-temperature strength and resistance to slagging are needed
Chrome	38 and above	Good	Fair to good, depending on composition and manufacture	Excellent below 2800°F. Poor above that temp	Less expensive and somewhat less slag-resistant than magnesite. Same general type of applications
Silicon carbide	37 to above 38	Excellent	Superior	Fair to poor	Expensive. Used in contact with flames and for indirect heat transfer. Abrasion-resistant

[a] Resistance to slagging does not always control uses and applications. See last column under Remarks and context of chapter.

REPRESENTATIVE FUSION TEMPERATURES OF REFRACTORIES

	Fusing Temp, °C, of commercial refractories
Fused alumina	1750—2000
Bauxite	1565—2000
Mullite	1650—1820
Fireclay	1500—1750
Silica	1685—1800
Silicon carbide	1800—2240
Magnesite	2150—2165
Chrome	1850—2050
Spinel ($MgO.Al_2O_3$	2135

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GAS SAVINGS WITH PREHEATED AIR

1. The heat salvaged by recuperation may be utilized by any of the following means depending upon the process involved:
   a. The volume of gas used for a given job may be decreased.
   b. Production may be increased because of the greater quantity of heat available.
   c. Temperatures of the furnace may be increased.

2. Mathematical formulae is given below have been established for calculating the possible gas savings and theoretical probable increase in production due to preheated air:
   a. Formula for gas savings calculation

$$S = \frac{A}{G - F_G + A} \times 100.$$

S = per cent gas savings.
A = heat in air, Btu per cu ft of gas.
G = Average gross heating value of gas per cu ft.
F_G = flue loss above room temperature including latent heat of vaporization, Btu, per cu ft of gas.

   b. Formula for calculating possible increase in production.

$$S_w = \frac{P}{W_1} \times 100.$$

Where

S_w = percentage increase in work.
P = heat introduced by preheated air, Btu per hr above room temperature.
W_1 = heat absorbed by work with no preheat, Btu per hr.

3. Experimental tests have verified the correctness of the formula for
   a. Natural and coke oven gases (or any city gas.)
   b. Either reducing, neutral or oxidizing furnace atmospheres.
   c. Flue gas temperatures from 1400-2500° F.
   d. Preheated air temperatures from 80-1624° F.

4. From the results obtained it is concluded that the formula given in (2) is correct for all industrial gas furnace applications.

5. Gas savings in excess of 40 per cent have resulted when burning natural gas with preheated air at approximately 1600° F. The practicability of air preheated in excess of that temperature seems doubtful since the economic limit from the standpoint of investment for most installations would be exceeded.

With permission, "Surface Combustion Industrial Heating Handbook."

FUEL CONSUMPTION OF GAS ENGINES

The amount of gas required per hp hour is dependent upon the efficiency of the engine and the percentage of full load at which it is operating. As the hp output of the engine decreases, the fuel consumption per hp hour increases. For estimating purposes, the following figures may safely be used.

Per Cent of full load	Btu per hp hr
100	10,200
75	11,200
50	14,500
25	20,600

Inasmuch as most engines operate between 75 and 100 per cent of full load, the accepted practice is to figure 11,200 Btu per hp hour.

BTU PER BRAKE HORSEPOWER HOUR

Per Cent load	Small Bore below 7"	Large 5ore above 7"
100%	10,200	9,700
90%	10,300	9,900
80%	10,800	10,200
70%	11,300	10,900
60%	13,000	11,800
50%	14,500	13,000
40%	16,500	14,800
30%	19,000	17,000
20%	23,000	20,500

The above figures do not include the power required to operate the auxiliaries such as: cooling water pump, fan charging generator, etc.

The heat to be dissipated in a gas engine is approximately as follows:

Cooling water 3000 Btu per BHP hour or 50 Btu per minute per BHP.

Exhaust 3500 Btu per BHP hour or 59 Btu per minute per BHP.

The formula for figuring the quantity of cooling water required is as follows:

$$GPM = \frac{BHP \times Btu}{T \times 8.33}$$

where

GPM = Gallons per minute of cooling water

BHP = Brake horsepower load on engine

Btu = Heat to be dissipated — Btu per minute

T = Difference in cooling water temperature in and out.

The heat balance of a natural gas engine at full load is approximately as follows:

Brake horsepower	25%
*Friction	7%
Cooling Water	30%
Exhaust	35%
Radiation	3%

*The heat generated in friction is dissipated in the cooling water and radiation.

AGA Gas Engine Handbook.

BELLAMY DEMAND-CHARGE RATE FORMULA

For All Load Factors

$$\text{Demand-charge per Mcf gas delivered} = \frac{3.288 \times DC}{LF}$$

Where

DC = Demand-charge per Mcf of billing demand per month

LF = Load factor

Therefore,

$$\text{Price per Mcf of gas delivered} = \frac{3.288 \times DC}{LF} + \text{commodity charge}$$

Example:

(Assumed Gas Rate)

Demand charge = $2.10 per Mcf billing demand per month

Commodity charge = 21c per Mcf of gas delivered

To determine price of gas at 70 per cent load factor

Then

$$\text{Gas price per Mcf} = \frac{3.288 \times 210}{70} + 21 = 9.86 + 21 = 30.86c$$

HEATING VALUE OF PETROLEUM OILS

Crude Oils, Fuel Oils, and Kerosene

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
10	1. 0000	8. 337	10, 300	18, 540	154, 600	9, 740	17, 540	146, 200	**10**
11	. 9930	8. 279	10, 330	18, 590	153, 900	9, 770	17, 580	145, 600	11
12	. 9861	8. 221	10, 360	18, 640	153, 300	9, 790	17, 620	144, 900	12
13	. 9792	8. 164	10, 390	18, 690	152, 600	9, 810	17, 670	144, 200	13
14	. 9725	8. 108	10, 410	18, 740	152, 000	9, 840	17, 710	143, 600	14
15	. 9659	8. 053	10, 440	18, 790	151, 300	9, 860	17, 750	142, 900	**15**
16	. 9593	7. 998	10, 470	18, 840	150, 700	9, 880	17, 790	142, 300	16
17	. 9529	7. 944	10, 490	18, 890	150, 000	9, 900	17, 820	141, 600	17
18	. 9465	7. 891	10, 520	18, 930	149, 400	9, 920	17, 860	140, 900	18
19	. 9402	7. 839	10, 540	18, 980	148, 800	9, 940	17, 900	140, 300	19
20	. 9340	7. 787	10, 570	19, 020	148, 100	9, 960	17, 930	139, 600	**20**
21	. 9279	7. 736	10, 590	19, 060	147, 500	9, 980	17, 960	139, 000	21
22	. 9218	7. 686	10, 620	19, 110	146, 800	10, 000	18, 000	138, 300	22
23	. 9159	7. 636	10, 640	19, 150	146, 200	10, 020	18, 030	137, 700	23
24	. 9100	7. 587	10, 660	19, 190	145, 600	10, 040	18, 070	137, 100	24
25	. 9042	7. 538	10, 680	19, 230	145, 000	10, 050	18, 100	136, 400	**25**
26	. 8984	7. 490	10, 710	19, 270	144, 300	10, 070	18, 130	135, 800	26
27	. 8927	7. 443	10, 730	19, 310	143, 700	10, 090	18, 160	135, 200	27
28	. 8871	7. 396	10, 750	19, 350	143, 100	10, 110	18, 190	134, 600	28
29	. 8816	7. 350	10, 770	19, 380	142, 500	10, 120	18, 220	133, 900	29
30	. 8762	7. 305	10, 790	19, 420	141, 800	10, 140	18, 250	133, 300	**30**
31	. 8708	7. 260	10, 810	19, 450	141, 200	10, 150	18, 280	132, 700	31
32	. 8654	7. 215	10, 830	19, 490	140, 600	10, 170	18, 310	132, 100	32
33	. 8602	7. 171	10, 850	19, 520	140, 000	10, 180	18, 330	131, 500	33
34	. 8550	7. 128	10, 860	19, 560	139, 400	10, 200	18, 360	130, 900	34
35	. 8498	7. 085	10, 880	19, 590	138, 800	10, 210	18, 390	130, 300	**35**
36	. 8448	7. 043	10, 900	19, 620	138, 200	10, 230	18, 410	129, 700	36
37	. 8398	7. 001	10, 920	19, 650	137, 600	10, 240	18, 430	129, 100	37
38	. 8348	6. 960	10, 940	19, 680	137, 000	10, 260	18, 460	128, 500	38
39	. 8299	6. 920	10, 950	19, 720	136, 400	10, 270	18, 480	127, 900	39
40	. 8251	6. 879	10, 970	19, 750	135, 800	10, 280	18, 510	127, 300	**40**
41	. 8203	6. 839	10, 990	19, 780	135, 200	10, 300	18, 530	126, 700	41
42	. 8155	6. 799	11, 000	19, 810	134, 700	10, 310	18, 560	126, 200	42
43	. 8109	6. 760	11, 020	19, 830	134, 100	10, 320	18, 580	125, 600	43
44	. 8063	6. 722	11, 030	19, 860	133. 500	10, 330	18, 600	125, 000	44
45	. 8017	6. 684	11, 050	19, 890	132, 900	10, 340	18, 620	124, 400	**45**
46	. 7972	6. 646	11, 070	19, 920	132, 400	10, 360	18, 640	123, 900	46
47	. 7927	6. 609	11, 080	19, 940	131, 900	10, 370	18, 660	123, 300	47
48	. 7883	6. 572	11, 100	19, 970	131, 200	10, 380	18, 680	122, 800	48
49	7839	6. 536	11, 110	20, 000	130, 700	10, 390	18, 700	122, 200	49

Bureau of Standards, Misc. Publication No. 97.

Tabel 1.

Volatile Petroleum Products

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
50	0. 7796	6. 500	11, 120	20, 020	130, 100	10, 400	18, 720	121, 700	**50**
51	. 7753	6. 464	11, 140	20, 050	129, 600	10, 410	18, 740	121, 100	51
52	. 7711	6. 429	11, 150	20, 070	129, 000	10, 420	18, 760	120, 600	52
53	. 7669	6. 394	11, 160	20, 100	128, 500	10, 430	18, 780	120, 100	53
54	. 7628	6. 360	11, 180	20, 120	128, 000	10, 440	18, 800	119, 500	54
55	. 7587	6. 326	11, 190	20, 140	127, 400	10, 450	18, 810	119, 000	**55**
56	. 7547	6. 292	11, 200	20, 170	126, 900	10, 460	18, 830	118, 500	56
57	. 7507	6. 258	11, 220	20, 190	126, 400	10, 470	18, 850	118, 000	57
58	. 7467	6. 225	11, 230	20, 210	125, 800	10, 480	18, 870	117, 500	58
59	. 7428	6. 193	11, 240	20, 230	125, 300	10, 490	18, 880	116, 900	59
60	. 7389	6. 160	11, 250	20, 260	124, 800	10, 500	18, 900	116, 400	**60**
61	. 7351	6. 128	11, 270	20, 280	124, 300	10, 510	18, 920	115, 900	61
62	. 7313	6. 097	11, 280	20, 300	123, 700	10, 520	18, 930	115, 400	62
63	. 7275	6. 065	11, 290	20, 320	123, 200	10, 530	18, 950	114, 900	63
64	. 7238	6. 034	11, 300	20, 340	122, 700	10, 540	18, 960	114, 400	64
65	. 7201	6. 004	11, 310	20, 360	122, 200	10, 540	18, 980	113, 900	**65**
66	. 7165	5. 973	11, 320	20, 380	121, 700	10, 550	18, 990	113, 400	66
67	. 7128	5. 943	11, 330	20, 400	121, 200	10, 560	19, 010	112, 900	67
68	. 7093	5. 913	11, 340	20, 420	120, 700	10, 570	19, 020	112, 500	68
69	. 7057	5. 884.	11, 350	20, 440	120, 200	10, 580	19, 040	112, 000	69
70	. 7022	5. 855	11, 360	20, 460	119, 800	10, 580	19, 050	111, 500	**70**
72	. 6953	5. 797	11, 380	20, 490	118, 800	10, 600	19, 080	110, 600	72
74	. 6886	5. 741	11, 400	20, 530	117, 900	10, 610	19, 100	109, 700	74
76	. 6819	5. 685	11, 420	20, 560	116, 900	10, 630	19, 130	108, 800	76
78	. 6754	5. 631	11, 440	20, 600	116, 000	10, 640	19, 150	107, 900	78
80	. 6690	5. 578	11, 460	20, 630	115, 100	10, 650	19, 180	107, 000	**80**
82	. 6628	5. 526	11, 480	20, 660	114, 200	10, 670	19, 200	106, 100	82
84	. 6566	5. 474	11, 490	20, 690	113, 300	10, 680	19, 220	105, 200	84
86	. 6506	5. 424	11, 510	20, 720	112, 400	10, 690	19, 240	104, 400	86
88	. 6446	5. 375	11, 530	20, 750	111, 500	10, 700	19, 260	103, 500	88
90	. 6388	5. 326	11, 540	20, 780	110, 700	10, 710	19, 280	102, 700	**90**
92	. 6331	5. 278	11, 560	20, 810	109, 800	10, 720	19, 300	101, 900	92
94	. 6275	5. 232	11, 570	20, 830	109, 000	10, 740	19, 320	101, 100	94
96	. 6220	5. 186	11, 590	20, 860	108, 100	10, 750	19, 340	100, 300	96
98	. 6166	5. 140	11, 600	20, 880	107, 300	10, 760	19, 360	99, 500	98
100	. 6112	5. 096	11, 620	20, 910	106, 500	10, 770	19, 380	98, 700	**100**
105	. 5983	4. 988	11, 650	20, 970	104, 600	10, 790	19, 420	96, 800	105
110	. 5859	4. 885	11, 680	21, 020	102, 700	10, 810	19, 460	95, 100	110
115	. 5740	4. 786	11, 710	21, 070	100, 900	10, 830	19, 490	93, 300	115
120	. 5626	4. 691	11, 740	21, 120	99, 100	10, 850	19, 530	91, 600	120
125	. 5517	4. 599	11, 760	21, 170	97, 400	10, 860	19, 560	90, 000	**125**
130	. 5411	4. 511	11, 790	21, 210	95, 700	10, 880	19, 590	88, 400	130
135	. 5310	4. 427	11, 810	21, 250	94, 100	10, 900	19, 610	86, 800	135
140	. 5212	4. 345	11, 830	21, 290	92, 500	10, 910	19, 640	85, 300	140
145	. 5118	4. 267	11, 850	21, 330	91, 000	10, 920	19, 660	83, 900	145

Table 2.

HEATING VALUE OF PETROLEUM OILS

In most practical applications of the combustion of petroleum products, the process is carried out at constant pressure (atmospheric) and the water vapor formed in combustion is not condensed. For such processes, therefore, the net heat of combustion at constant pressure is the more significant quantity in making comparisons of fuels and in calculating the efficiencies of heating appliances.

Heats of Combustion of Crude Oils, Fuel Oils, and Kerosenes

The data on heats of combustion (heating values) given in Table I apply to petroleum oils free from water, ash, and sulphur with an estimated accuracy of 1 per cent. These data are based on experimental results obtained, on a total of 630 petroleum oils from 8 States and 10 foreign countries, by 5 groups of observers.

Heats of Combustion of Volatile Petroleum Products

The data on heats of combustion (heating values) given in Table II apply to volatile petroleum liquids in general with an estimated accuracy of 1 per cent. The values given are probably too high by 1 or 2 per cent for products containing unusually large amounts of aromatic hydrocarbons; for example, "vapor phase cracked" gasoline. The tabulated values should be increased by about 1 per cent to yield corresponding value for the heats of combustion of vapor (vaporized product); that is, for those instances in which the latent heat of vaporization is supplied by the external surroundings and not by the combustion of the product.

Bureau of Standards, Misc. Publication No. 97.

Heating Value of Fuel Oils

It is common practice in power applications to measure the specific gravity of fuel oils in degrees Baume rather than API as provided above. The following relation, based upon degrees Baume, is applicable to commercial fuel oils (specific (specific gravity 35 to 10 deg Bé):

Higher Heating Value (Btu/pound) =

$$18{,}250 + 40 \text{ (deg Bé} - 10)$$

Commercial Standards, CS 12-29

OIL TEMPERATURE CORRECTION FACTORS

Oil Temperature Correction Factors—to 60° F.

Observed Temperature ° F.	Degrees A. P. I. 5.0° to 9.9°	10.0° to 14.9°	15.0° to 19.9°	20.0° to 24.9°	25.0° to 29.9°	30.0° to 34.9°	35.0° to 39.9°	40.0° to 49.9°	50.0° to 59.9°
0	1.0215	1.0227	1.0235	1.0243	1.0251	1.0262	1.0276	1.0301	1.0347
2	1.0208	1.0219	1.0227	1.0235	1.0243	1.0253	1.0267	1.0291	1.0335
4	1.0201	1.0211	1.0219	1.0226	1.0234	1.0244	1.0258	1.0281	1.0324
6	1.0193	1.0203	1.0211	1.0218	1.0226	1.0236	1.0248	1.0271	1.0312
8	1.0186	1.0196	1.0203	1.0210	1.0217	1.0227	1.0239	1.0261	1.0301
10	1.0179	1.0188	1.0195	1.0202	1.0209	1.0218	1.0230	1.0251	1.0290
12	1.0171	1.0180	1.0187	1.0194	1.0201	1.0209	1.0221	1.0241	1.0278
14	1.0164	1.0173	1.0179	1.0185	1.0192	1.0200	1.0212	1.0231	1.0267
16	1.0157	1.0165	1.0171	1.0177	1.0184	1.0192	1.0203	1.0221	1.0255
18	1.0150	1.0158	1.0164	1.0169	1.0175	1.0183	1.0194	1.0211	1.0244
20	1.0144	1.0150	1.0156	1.0161	1.0167	1.0174	1.0184	1.0201	1.0232
22	1.0137	1.0142	1.0148	1.0153	1.0159	1.0165	1.0175	1.0191	1.0220
24	1.0129	1.0135	1.0140	1.0144	1.0150	1.0156	1.0166	1.0181	1.0209
26	1.0122	1.0127	1.0132	1.0136	1.0142	1.0148	1.0156	1.0171	1.0197
28	1.0115	1.0120	1.0125	1.0128	1.0133	1.0139	1.0147	1.0161	1.0186
30	1.0108	1.0112	1.0117	1.0120	1.0125	1.0130	1.0138	1.0151	1.0174
32	1.0100	1.0105	1.0109	1.0112	1.0117	1.0121	1.0129	1.0141	1.0162
34	1.0093	1.0097	1.0101	1.0104	1.0108	1.0112	1.0120	1.0131	1.0151
36	1.0085	1.0089	1.0093	1.0096	1.0100	1.0104	1.0110	1.0121	1.0139
38	1.0078	1.0082	1.0085	1.0088	1.0091	1.0095	1.0101	1.0110	1.0128
40	1.0071	1.0074	1.0077	1.0080	1.0083	1.0087	1.0092	1.0100	1.0116
42	1.0064	1.0067	1.0069	1.0072	1.0075	1.0078	1.0082	1.0090	1.0104
44	1.0057	1.0060	1.0062	1.0064	1.0066	1.0069	1.0073	1.0080	1.0093
46	1.0049	1.0052	1.0054	1.0056	1.0058	1.0061	1.0064	1.0070	1.0081
48	1.0042	1.0045	1.0046	1.0048	1.0050	1.0052	1.0055	1.0060	1.0070
50	1.0035	1.0037	1.0038	1.0040	1.0042	1.0043	1.0046	1.0050	1.0058
52	1.0028	1.0029	1.0030	1.0032	1.0034	1.0035	1.0037	1.0041	1.0046
54	1.0021	1.0022	1.0023	1.0024	1.0025	1.0026	1.0028	1.0030	1.0035
56	1.0014	1.0014	1.0015	1.0016	1.0017	1.0018	1.0018	1.0020	1.0023
58	1.0007	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009	1.0010	1.0012
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
62	.9993	.9993	.9992	.9992	.9992	.9991	.9991	.9990	.9988
64	.9986	.9986	.9985	.9984	.9983	.9982	.9982	.9980	.9977
66	.9979	.9978	.9977	.9976	.9975	.9974	.9972	.9970	.9965
68	.9972	.9971	.9970	.9968	.9966	.9965	.9963	.9960	.9954
70	.9965	.9963	.9962	.9960	.9958	.9957	.9954	.9950	.9942
72	.9958	.9956	.9954	.9952	.9950	.9949	.9945	.9940	.9930
74	.9951	.9949	.9946	.9944	.9942	.9940	.9936	.9929	.9919
76	.9943	.9941	.9938	.9936	.9934	.9932	.9927	.9919	.9907
78	.9937	.9934	.9931	.9929	.9926	.9923	.9918	.9909	.9896
80	.9930	.9927	.9924	.9921	.9918	.9914	.9909	.9899	.9884
82	.9923	.9919	.9916	.9913	.9910	.9905	.9899	.9889	.9871
84	.9916	.9912	.9908	.9905	.9901	.9896	.9890	.9879	.9860
86	.9909	.9904	.9900	.9897	.9893	.9888	.9880	.9869	.9848
88	.9902	.9897	.9893	.9889	.9884	.9879	.9871	.9859	.9837
90	.9895	.9890	.9885	.9881	.9876	.9870	.9862	.9849	.9825
92	.9888	.9883	.9877	.9873	.9868	.9861	.9853	.9839	.9813
94	.9881	.9875	.9870	.9865	.9860	.9852	.9844	.9829	.9802
96	.9874	.9867	.9862	.9857	.9852	.9844	.9834	.9819	.9790
98	.9867	.9860	.9855	.9849	.9843	.9835	.9825	.9809	.9779
100	.9860	.9853	.9847	.9841	.9835	.9827	.9816	.9799	.9767
102	.9853	.9846	.9839	.9833	.9827	.9818	.9807	.9789	.9755
104	.9846	.9839	.9832	.9826	.9818	.9809	.9798	.9778	.9743
106	.9838	.9831	.9824	.9818	.9810	.9801	.9789	.9768	.9731
108	.9832	.9824	.9817	.9810	.9802	.9792	.9780	.9758	.9720
110	.9825	.9817	.9810	.9802	.9794	.9783	.9771	.9748	.9708
112	.9818	.9809	.9802	.9794	.9786	.9775	.9762	.9738	.9696
114	.9811	.9802	.9794	.9786	.9777	.9766	.9753	.9728	.9685
116	.9804	.9795	.9786	.9778	.9769	.9758	.9743	.9718	.9673
118	.9797	.9788	.9781	.9770	.9760	.9749	.9734	.9708	.9662
120	.9790	.9781	.9772	.9762	.9752	.9741	.9725	.9698	.9650

Compiled from Bureau of Standards Circular C410 (1936).

Multiply the volume of oil in the tank or car at the observed temperature by these factors to get the volume at 60 deg F.

ANNUITY TABLE

Amount per year resulting in an annuity of one dollar after number of years shown below.

Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000
2	0.495050	.0.493827	0.492611	0.491400	0.490196	0.488998	0.487805	0.485437	0.483092	0.480769	0.478469	0.476190
3	.326755	.325137	.323530	.321934	.320349	.318773	.317209	.314110	.311052	.308034	.305055	.302115
4	.242624	.240818	.239027	.237251	.235490	.233744	.232012	.228012	.225228	.221921	.218669	.215471
5	.192159	.190247	.188355	.186481	.184627	.182792	.180975	.177396	.173891	.170456	.167092	.163797
6	.158526	.156550	.154597	.152668	.150762	.148878	.147017	.143363	.139796	.136315	.132920	.129607
7	.134512	.132495	.130506	.128545	.126610	.124701	.122820	.119135	.115553	.112072	.108691	.105405
8	.116510	.114467	.112456	.110477	.108528	.106610	.104722	.101036	.097468	.094015	.090674	.087444
9	.102515	.100457	.098434	.096446	.094493	.092574	.090690	.087022	.083486	.080080	.076799	.073641
10	.091327	.089259	.087231	.085241	.083291	.081379	.079505	.075868	.072378	.069029	.065820	.062745
11	.082178	.080106	.078077	.076092	.074149	.072248	.070389	.066793	.063357	.060076	.056947	.053963
12	.074560	.072487	.070462	.068484	.066552	.064666	.062825	.059277	.055902	.052695	.049651	.046763
13	.068118	.066048	.064030	.062062	.060144	.058275	.056456	.052960	.049651	.046522	.043567	.040779
14	.062602	.060537	.058526	.056571	.054669	.052820	.051024	.047585	.044345	.041297	.038433	.035746
15	.057825	.055766	.053767	.051825	.049941	.048114	.046342	.042963	.039795	.036830	.034059	.031474
16	.053650	.051599	.049611	.047685	.045820	.044015	.042270	.038952	.035858	.032977	.030300	.027817
17	.049970	.047928	.045953	.044043	.042199	.040418	.038699	.035445	.032425	.029629	.027046	.024664
18	.046702	.044670	.042709	.040817	.038993	.037237	.035546	.032357	.029413	.026702	.024212	.021930
19	.043782	.041761	.039814	.037940	.036139	.034407	.032745	.029621	.026753	.024128	.021730	.019547
20	.041157	.039147	.037216	.035361	.033582	.031876	.030243	.027185	.024393	.021852	.019546	.017460
21	.038785	.036787	.034872	.033037	.031280	.029601	.027996	.025005	.022289	.019832	.017617	.015624
22	.036631	.034647	.032747	.030932	.029199	.027546	.025971	.023046	.020406	.018032	.015905	.014005
23	.034668	.032696	.030814	.029019	.027309	.025682	.024137	.021278	.018714	.016422	.014382	.012572
24	.032871	.030913	.029047	.027273	.025587	.023987	.022471	.019679	.017189	.014978	.013023	.011300
25	.031220	.029276	.027428	.025674	.024012	.022439	.020952	.018227	.015811	.013679	.011806	.010161
26	.029699	.027769	.025938	.024205	.022567	.021021	.019564	.016564	.014561	.0125071	.0107154	.0091590
27	.028293	.026377	.024564	.022852	.021239	.019719	.018292	.015697	.013426	.0114481	.0097349	.0082576
28	.026990	.025088	.023293	.021603	.020013	.018521	.017123	.014593	.012392	.0104889	.0088520	.0074510
29	.025778	.023891	.022115	.020445	.018880	.017415	.016046	.013580	.011449	.0096185	.0080557	.0067281
30	.024650	.022778	.021019	.019371	.017830	.016392	.015051	.012649	.010586	.0088274	.0073364	.0060927
31	.023596	.021739	.019999	.018372	.016855	.015443	.014132	.011792	.009797	.0081073	.0066856	.0054962
32	.022611	.020768	.019047	.017442	.015949	.014563	.013280	.011002	.009073	.0074508	.0060962	.0049717
33	.021687	.019859	.018156	.016572	.015104	.013745	.012490	.010273	.008408	.0068516	.0055617	.0044994
34	.020819	.019007	.017322	.015760	.014315	.012982	.011755	.009598	.007797	.0063041	.0050766	.0040737
35	.020002	.018206	.016539	.014998	.013577	.012270	.011072	.008974	.007234	.0058033	.0046358	.0036897
36	.019233	.017452	.015804	.014284	.012887	.011606	.010434	.008395	.006715	.0053447	.0042350	.0033431
37	.018507	.016741	.015112	.013613	.012240	.010984	.009840	.007857	.006237	.0049244	.0038703	.0030299
38	.017821	.016070	.014459	.012982	.011632	.010402	.009284	.007358	.005795	.0045389	.0035382	.0027469
39	.017171	.015436	.013844	.012388	.011061	.009856	.008765	.006894	.005387	.0041851	.0032356	.0024910
40	.016556	.014836	.013262	.011827	.010523	.009343	.008278	.006462	.005009	.0038602	.0029596	.0022594
41	.015972	.014268	.012712	.011298	.010017	.008862	.007822	.006059	.004660	.0035615	.0027079	.0020498
42	.015417	.013729	.012192	.010798	.009540	.008409	.007395	.005683	.004336	.0032868	.0024781	.0018600
43	.014890	.013217	.011698	.010325	.009090	.007982	.006993	.005333	.004036	.0030341	.0022684	.0016880
44	.014388	.012730	.011230	.009878	.008665	.007581	.006616	.005006	.003758	.0028015	.0020767	.0015322
45	.013910	.012268	.010785	.009453	.008262	.007202	.006262	.004700	.003500	.0025873	.0019017	.00139
46	.013453	.011827	.010363	.009051	.007882	.006845	.005928	.004415	.003260	.0023899	.0017416	.0012620
47	.013018	.011407	.009961	.008669	.007522	.006507	.005614	.004148	.003037	.0022080	.0015952	.0011468
48	.012602	.011006	.009578	.008306	.007181	.006189	.005318	.003897	.0023897	.0020403	.0014614	.0010415
49	.012204	.010623	.009213	.007962	.006857	.005887	.005040	.003664	.002639	.0018856	.0013389	.0009459
50	.011823	.010258	.008865	.007634	.006550	.005602	.004777	.003444	.002460	.0017429	.0012269	.0008592

COMPOUND INTEREST

Amount of one dollar at compound interest after number of years indicated.

Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	$1.02000	$1.02500	$1.03000	$1.03500	$1.04000	$1.04500	$1.05000	$1.06000	$1.07000	$ 1.08000	$1.09000	$ 1.10000
2	1.04040	1.05062	1.06090	1.07122	1.08160	1.09203	1.10250	1.12360	1.14490	1.16640	1.18810	1.21000
3	1.06121	1.07689	1.09273	1.10872	1.12486	1.14117	1.15763	1.19102	1.22504	1.25971	1.29503	1.33100
4	1.08243	1.10381	1.12551	1.14752	1.16986	1.19252	1.21551	1.26248	1.31080	1.36049	1.41158	1.46410
5	1.10408	1.13141	1.15927	1.18769	1.21665	1.24618	1.27628	1.33823	1.40255	1.46933	1.53862	1.61051
6	1.12616	1.15969	1.19405	1.22926	1.26532	1.30226	1.34010	1.41852	1.50073	1.58678	1.67710	1.77156
7	1.14869	1.18869	1.22987	1.27228	1.31593	1.36086	1.40710	1.50363	1.60578	1.71382	1.82804	1.94872
8	1.17166	1.21840	1.26677	1.31681	1.36857	1.42210	1.47746	1.59385	1.71819	1.85093	1.99256	2.14359
9	1.19509	1.24886	1.30477	1.36290	1.42331	1.48610	1.55133	1.68948	1.83846	1.99900	2.17189	2.35795
10	1.21899	1.28008	1.34392	1.41060	1.48024	1.55297	1.62889	1.79085	1.96715	2.15892	2.36736	2.59374
11	1.24337	1.31209	1.38423	1.45997	1.53945	1.62285	1.71034	1.89830	2.10485	2.33164	2.58043	2.85312
12	1.26824	1.34489	1.42576	1.51107	1.60103	1.69588	1.79586	2.01220	2.25219	2.51817	2.81266	3.13843
13	1.29361	1.37851	1.46853	1.56396	1.66507	1.77220	1.88565	2.13293	2.40985	2.71962	3.06580	3.45227
14	1.31948	1.41297	1.51259	1.61869	1.73168	1.85194	1.97993	2.26090	2.57853	2.93719	3.34173	3.29773
15	1.34587	1.55830	1.55797	1.67535	1.80094	1.93528	2.07893	2.39656	2.75903	3.17217	3.64248	4.17725
16	1.37279	1.48451	1.60471	1.73399	1.87298	2.02237	2.18287	2.54035	2.95216	3.42594	3.97031	4.59497
17	1.40024	1.52162	1.65285	1.79467	1.94790	2.11338	2.69277	2.69277	3.15882	3.70002	4.32763	5.05447
18	1.42825	1.55966	1.70243	1.85749	2.02582	2.20848	2.40662	2.85434	3.37993	3.99602	4.71712	5.55992
19	1.45681	1.59865	1.75351	1.92250	2.10685	2.30786	2.52695	3.02560	3.61653	4.31570	5.14166	6.11591
20	1.48595	1.63862	1.80611	1.98979	2.19112	2.41171	2.65330	3.20714	3.86968	4.66096	5.60441	6.72750
21	1.51567	1.67958	1.86029	2.05943	2.27877	2.52024	2.78596	3.39956	4.14056	5.03383	6.10881	7.40025
22	1.54598	1.72157	1.91610	2.13151	2.36992	2.6365	2.92526	3.60354	4.43040	5.43654	6.65860	8.14027
23	1.57690	1.76461	1.97359	2.20611	2.46472	2.75217	3.07152	3.81975	4.74053	5.87146	7.25787	8.95430
24	1.60844	1.80873	2.03279	2.28333	2.56330	2.87601	3.22510	4.04893	5.07237	6.34118	7.91108	9.84973
25	1.64061	1.85394	2.09378	2.36324	2.66584	3.00543	3.38635	4.29187	5.42743	6.48848	8.62308	10.83471
26	1.67342	1.90029	2.15659	2.44596	2.77247	3.14068	3.55567	4.54938	5.80735	7.39635	9.39916	11.91818
27	1.70689	1.94780	2.22129	2.53157	2.88337	3.28201	3.73346	4.82235	6.21387	7.98806	10.24508	13.10999
28	1.74102	1.99650	2.28793	2.62017	2.99870	3.42970	3.92013	5.11169	6.64884	8.62711	11.16714	14.29000
29	1.77584	2.04640	2.35657	2.71188	3.11865	3.58404	4.11614	5.41839	7.11426	9.31727	12.17218	15.86309
30	1.81136	2.09757	2.42726	2.80679	3.24340	3.74532	4.32194	5.74349	7.61226	10.06266	13.26768	17.44940
31	1.84759	2.15000	2.50008	2.90503	3.37313	3.91386	4.53804	6.08810	8.14511	10.86767	14.46177	19.19434
32	1.88454	2.20376	2.57508	3.00671	3.50806	4.08998	4.76494	6.45339	8.71527	11.73708	15.76333	21.11378
33	1.92223	2.25885	2.65234	3.11194	3.64838	4.27403	5.00319	6.84059	9.32534	12.67605	17.18203	23.22515
34	1.96068	2.31532	2.73191	3.22086	3.79432	4.46636	5.25335	7.25103	9.97811	13.69013	18.72841	25.54767
35	1.99989	2.37321	2.81386	3.33359	3.94609	4.66735	5.51602	7.68609	10.67658	14.78534	20.41397	28.10244
36	2.03989	2.43254	2.89828	3.45027	4.10393	4.87738	5.79182	8.14725	11.42394	15.96817	22.25123	30.91268
37	2.08068	2.49335	2.98523	3.57103	4.26809	5.09686	6.08141	8.63609	12.22362	17.24563	24.25384	34.00395
38	2.12230	2.55568	3.07478	3.69601	4.43881	5.32622	6.38548	9.15425	13.07927	18.62528	26.43668	37.40434
39	2.16474	2.61957	3.16703	3.82537	4.61637	5.56590	6.70475	9.70351	13.99482	20.11530	28.81598	41.14478
40	2.20803	2.68506	3.26204	3.95926	4.80102	5.81636	7.03999	10.28572	14.97446	21.72452	31.40942	45.25926
41	2.25220	2.75219	3.35990	4.09783	4.99306	6.07810	7.39199	10.90286	16.02267	23.46248	34.23627	49.78518
42	2.29724	2.82100	3.46070	4.24126	5.19278	6.35161	7.76159	11.55703	17.14426	25.33948	37.31753	54.76370
43	2.34319	2.89152	3.56452	4.38970	5.40050	6.63744	8.14967	12.25045	18.34435	27.36664	40.67611	60.24007
44	2.39005	2.96381	3.67145	4.54334	5.61652	6.93612	8.55715	12.98548	19.62846	29.55597	44.33696	66.26408
45	2.43785	3.03790	3.78160	4.70236	5.84118	7.24825	8.98501	13.76461	21.00245	31.92045	48.32729	72.89048
46	2.48661	3.11385	3.89504	4.86694	6.07482	7.57442	9.43426	14.59049	22.47262	34.47409	52.67674	80.17953
47	2.53634	3.19169	4.01190	5.03782	6.31782	7.91527	9.90597	15.46592	24.04571	37.23201	57.41765	88.19749
48	2.58707	3.27149	4.13225	5.21359	6.57053	8.27145	10.40127	16.39387	25.72891	40.21057	62.58524	97.01723
49	2.63881	3.35328	4.25622	5.39606	6.83335	8.64367	10.92133	17.37750	27.52993	43.42742	68.21791	106.71896
50	2.69159	3.43711	4.38391	5.58493	7.10668	9.03264	11.46740	18.42015	29.45703	46.90161	74.35752	117.39085

PRESENT WORTH

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Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	98039	97561	97087	96618	96154	95691	95238	94340	93458	92593	91743	90909
2	96117	95181	94260	93351	92456	91573	097030	89000	87344	85734	84168	82645
3	94232	92860	91514	90194	88900	87630	86384	83962	81630	79383	79383	75131
4	92385	90595	88849	87144	85480	83856	82270	79209	76290	73503	70843	68301
5	90573	88385	86261	84197	82193	80245	78353	74726	71299	68058	64993	62092
6	88797	86230	83748	81350	79031	76790	74622	70496	66634	63017	59627	56447
7	87056	84127	81309	78599	75992	73483	71068	66506	62275	58349	54703	51316
8	85349	82075	78941	75941	73069	70319	67684	62741	58201	54027	50187	46651
9	83676	80073	76642	73373	70259	67290	64461	59190	54393	50025	46043	42410
10	82035	78120	74409	70892	67556	64393	61391	55839	50835	46319	42241	38554
11	80426	76214	72242	68495	64958	61620	58468	52679	47509	42888	38753	35049
12	78849	74356	70138	66178	62460	58966	55684	49697	44401	39711	35553	31863
13	77303	72542	68095	63940	60057	56427	53032	46884	41496	36770	32618	28966
14	75788	70773	66112	61778	57748	53997	50507	44230	38782	34046	29925	26333
15	74301	69047	64186	59689	55526	51672	48102	41727	36245	31524	27454	23939
16	72845	67363	62317	57671	53391	49447	45811	39365	33873	29189	25187	21763
17	71416	65720	60502	55720	51337	47318	43630	37136	31657	27027	23107	19784
18	70016	64117	58739	53836	49363	45280	41552	35034	29586	25025	21199	17986
19	68643	62553	57029	52016	47464	43330	39573	33051	27651	23171	19449	16351
20	67297	61027	55368	50257	45639	41464	37689	31180	25842	21455	17843	14864
21	65978	59539	53755	48557	43883	39679	35894	29416	24151	19866	16370	13513
22	64684	58086	52189	46915	42196	37970	34185	27751	22571	18394	15018	12285
23	63416	56670	50669	45329	40573	36335	32557	26180	21095	17032	12778	11168
24	62172	55288	49193	43796	39012	34770	31007	24698	19715	15770	12640	10153
25	60953	53939	47761	42315	37512	33273	29530	23300	18425	14602	11597	09230
26	59758	52623	46369	40884	36069	31840	28124	21981	17220	13520	10639	08391
27	58586	51340	45019	39501	34682	30469	26785	20737	16093	12519	09761	07628
28	57437	50088	43708	38165	33348	29157	25509	19563	15040	11591	08955	06934
29	56311	48866	42435	36875	32065	27901	24295	18456	14056	10733	08215	06304
30	55207	47674	41199	35628	30832	26700	23138	17411	13137	09938	07537	05731
31	54125	46511	39999	34423	29646	25550	22036	16425	12277	09202	06915	05210
32	53063	45377	38834	33259	28506	24450	20987	15496	11474	08520	06344	04736
33	52023	44270	37703	32134	27409	23397	19987	14619	10723	07889	05820	04306
34	51003	43191	36604	31048	26355	22390	19035	13791	10022	07305	05339	03914
35	50003	42137	35538	29998	25342	21425	18129	13011	09366	06763	04899	03558
36	49022	41109	34503	28983	24367	20503	17266	12274	08754	06262	06262	03235
37	48061	40107	33498	28003	23430	19620	16444	11579	08181	05799	04123	02941
38	47119	39128	32523	27056	22529	18775	15661	10924	07646	05369	03783	02673
39	46195	38174	31575	26141	21662	17967	14915	10306	07146	04971	03470	02430
40	45289	37243	30656	25257	20829	17193	14205	09722	06678	04603	03184	02209
41	44401	36335	29763	24403	20028	16453	13528	09172	06241	04262	04494	02009
42	43530	35448	28896	23578	19257	15744	12884	08653	05833	03946	02680	01826
43	42677	34584	28054	22781	18517	15066	12270	08163	05451	03654	02458	01660
44	41840	33740	27237	22010	17805	14417	11686	07701	05095	03383	02255	01509
45	41020	32917	26444	21266	17120	13796	11130	07265	04761	03133	02069	01372
46	40215	32115	25674	20547	16461	13202	10600	06854	04450	02901	01898	01247
47	39427	31331	24926	19852	15828	12634	10095	06466	04159	02686	01742	01134
48	38654	30567	24200	19181	15219	12090	09614	06100	03887	02487	01598	01031
49	37896	29822	23495	18532	14634	11569	09156	05755	03632	02303	01466	00937
50	37153	29094	22811	17905	14071	11071	08720	05429	03395	02132	01345	00852

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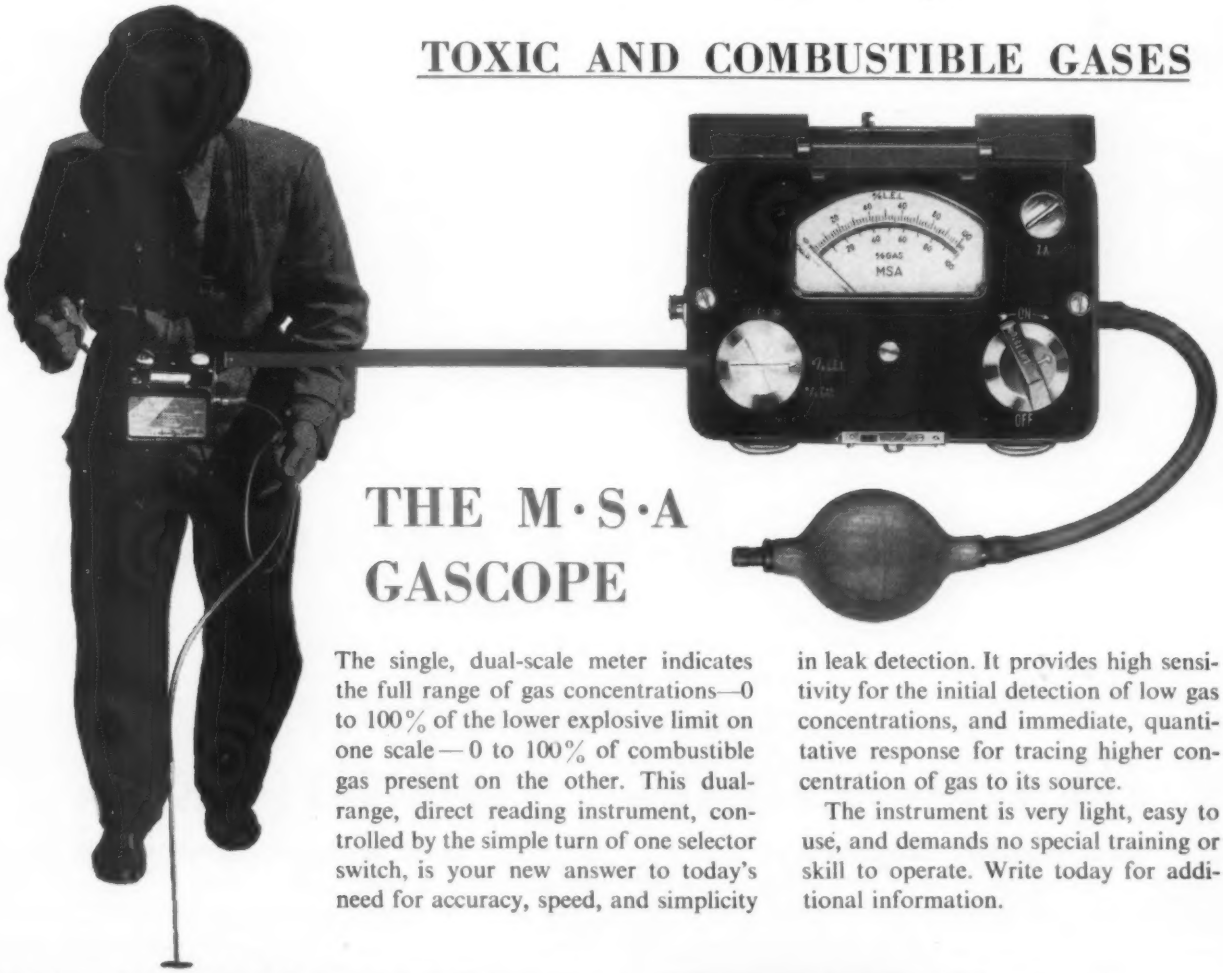
TOXIC AND COMBUSTIBLE GASES



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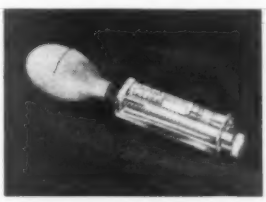

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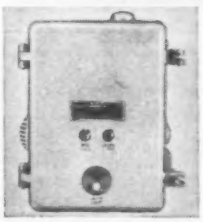
The CO Tester indicates CO in air from 0.001 to 0.10 percent by volume and is accurate in the presence of water and gasoline vapors. With a scrubber, it can be used for measuring CO in flue gases. Write for details.



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Whenever CO reaches a predetermined concentration, this instrument sets off a loud, audible warning and visible indication. Ideal protection in gas manufacturing plants, pumping or compressor stations and around gas holders. Write for details.

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Abbreviations for AGA Section References

OS — Operating Section
LAB — Laboratories
GM — General Management
AS —Accounting Section
I&CS — Industrial and Commercial Section
R&U-PAR — Domestic Gas Research and Utilization Bureau, PAR

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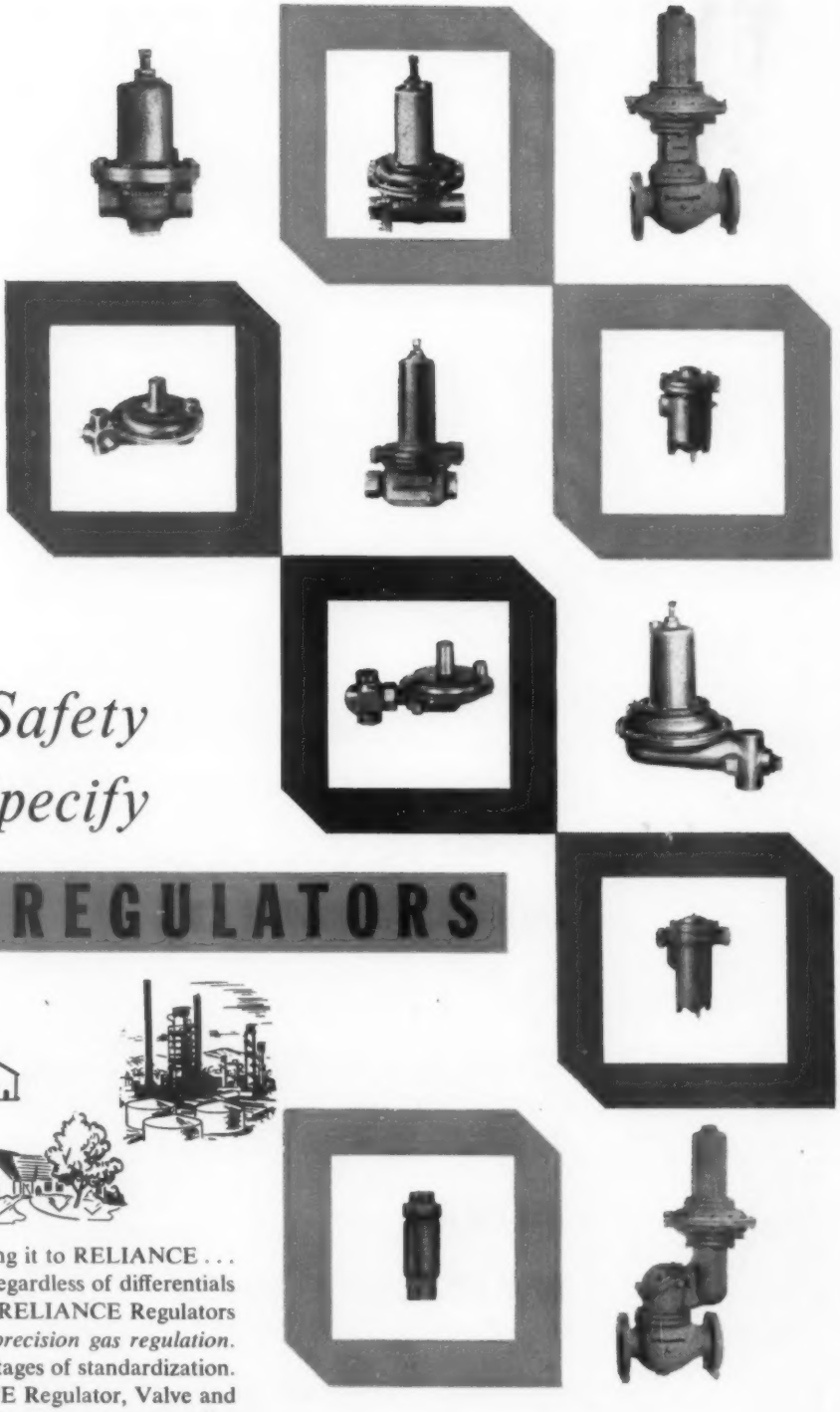

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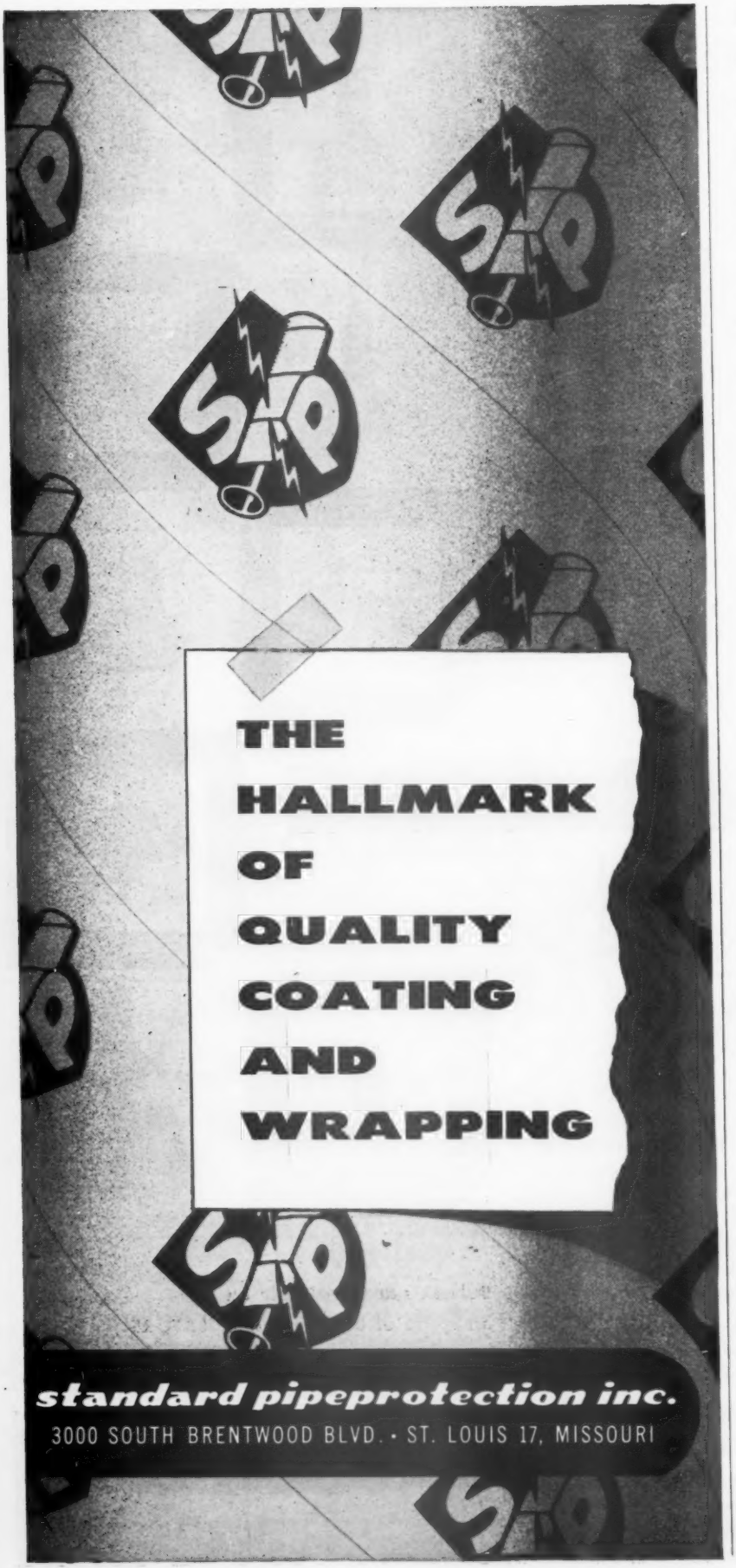

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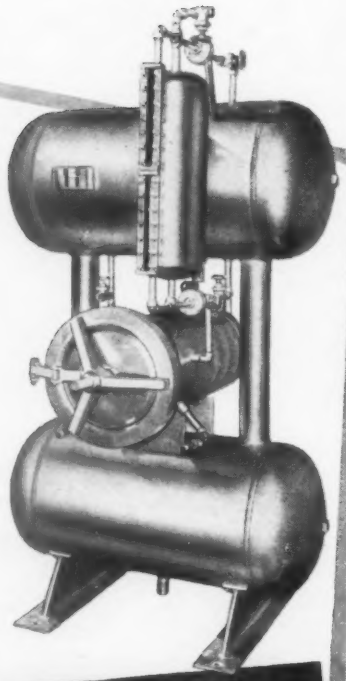

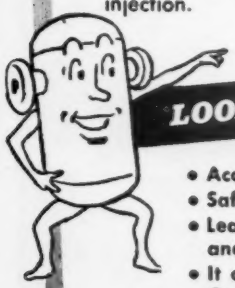

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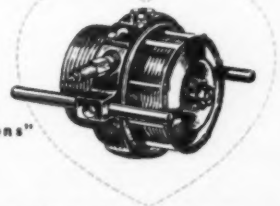
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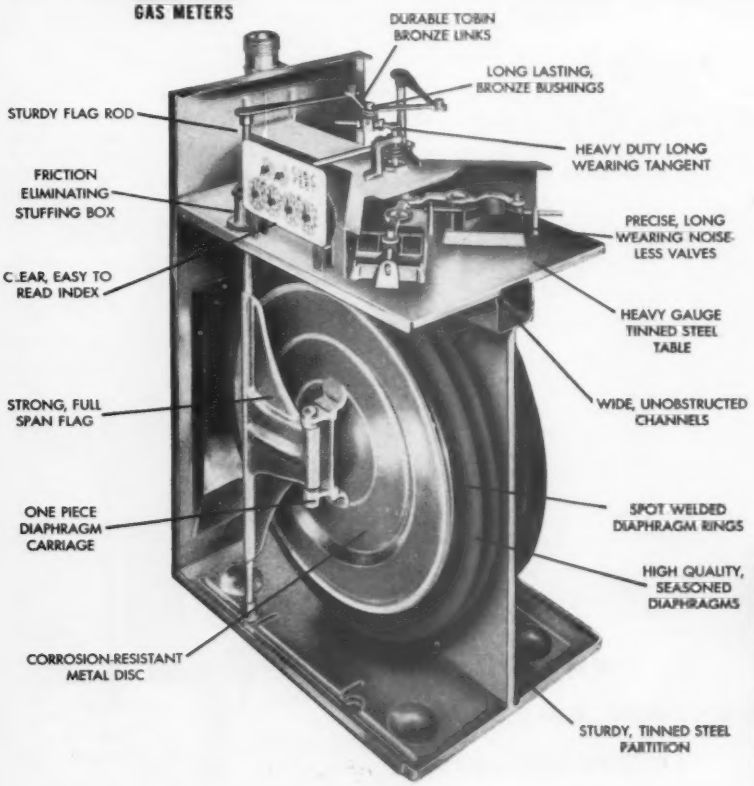
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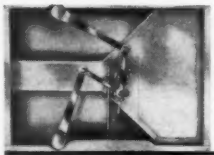

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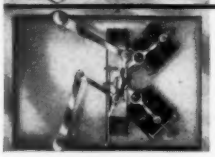

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	5	250	½	15½	11⅜	16⅝	2	6
	5	300	¾	15½	11⅜	16⅝	2	6
	10	400	¾	23½	13⅜	18½	5	3⅗
	20	600	1	40½	16⅛	22	5	2
	30	900	1¼	47½	18¼	26¼	5	1⅗
	60	1500	1½	118	25¼	33⅛	20	½
TYPE "B"	5	150	½	15½	11⅜	16⅝	2	6
	10	300	¾	23½	13⅜	18½	5	3⅗
	20	450	1	34	16⅛	22	5	2⅕
	30	600	1¼	47½	18¼	26¼	5	1⅗
	60	1300	1½	117	24	31⅜	10	⅗
TYPE "C"	6	600	1¼	35	14⅜	19¾	10	1⅖
	11	1100	2	68	19⅜	27¾	10	⅘
	25	2500	2½	156	25⅜	34	20	7/20
	40	4000	3	215	29¼	38½	50	⅓
	60	6000	4	400	36	45¼	100	1/10
	75	7500	4	400	36	45¼	100	1/10
TYPE "T"	2	80	½	8.3	7¾	12⅝	1	20
	2	100	½	8.3	7¾	12⅝	1	20
	2	140	½	8.3	7¾	12⅝	1	20
	5	150	½	15½	11⅝	16⅝	2	6
	5	210	½	15½	11⅝	16⅝	2	6
	5	250	½	15½	11⅝	16⅝	2	6
	5	300	¾	15½	11⅝	16⅝	2	6
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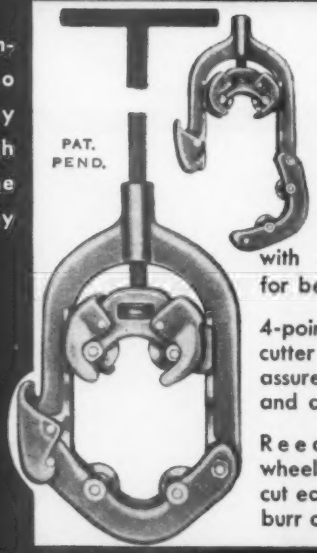

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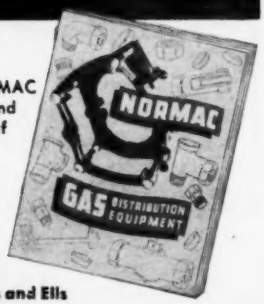

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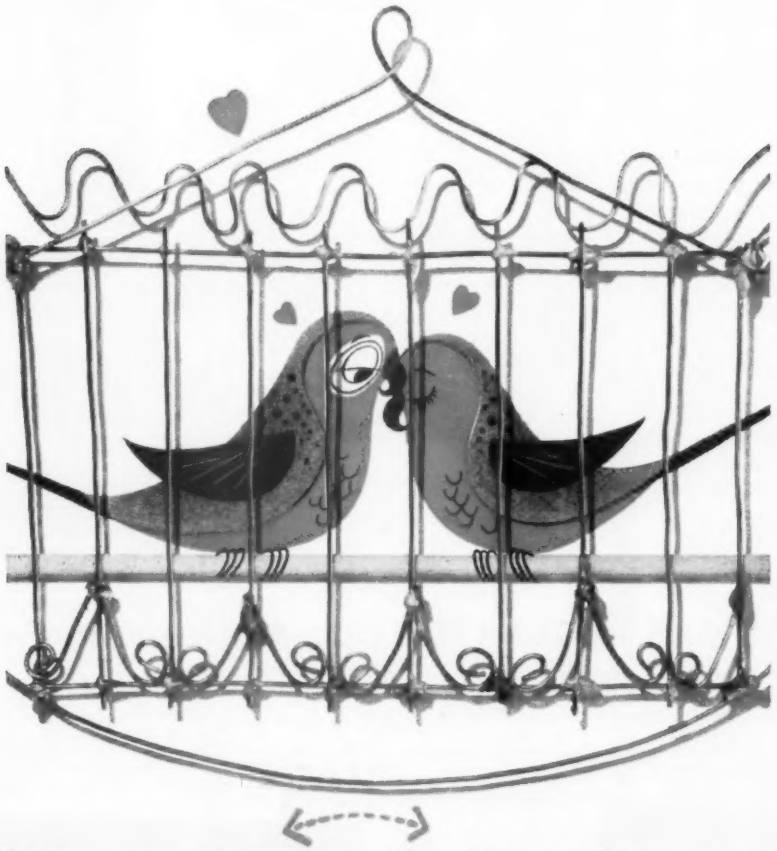

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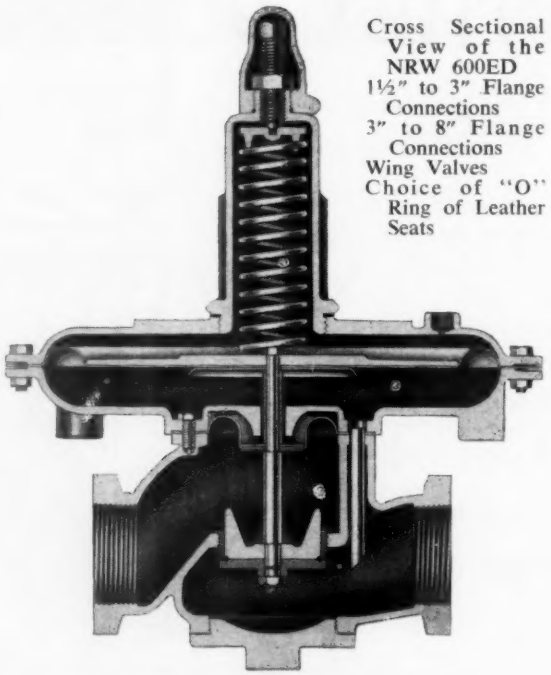

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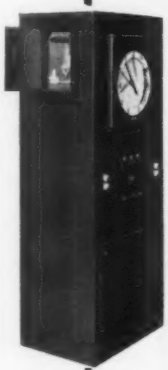

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Jan. 20—**Southern Gas Association** employee relations conference, Shamrock Hotel, Houston, Texas.

Jan. 26-27—**Fifth Annual Instrument Short Course,** sponsored by Southern California Meter Association and Los Angeles Harbor Junior College, Los Angeles Harbor Junior College, Wilmington, California.

Jan. 27—**Southern Gas Association** accident prevention conference, Jung Hotel, New Orleans, Louisiana.

Feb. 15-17—**National Association of Corrosion Engineers,** Corrosion short course for Pipeliners, Mayo Hotel, Tulsa, Oklahoma.

March 12-16—**National Association of Corrosion Engineers,** annual, Statler Hotel, New York, New York.

March 19-21—**Mid-West Gas Association,** Hotel Fontenelle, Omaha, Nebraska.

March 22-23—**New England Gas Association,** annual meeting, Statler Hotel, Boston, Massachusetts.

April 4-6—**American Gas Association,** General Management Section, spring conference, Conrad Hilton Hotel, Chicago, Illinois.

April 11-13—**Natural Gasoline Association of America,** annual, Texas Hotel, Fort Worth, Texas.

April 19-21—**Indiana Gas Association,** French Lick Springs Hotel, French Lick, Indiana.

April 23-25—**Southern Gas Association** convention, annual, Statler Hilton Hotel, Dallas, Texas.

May 6-9—**Liquefied Petroleum Gas Association,** convention and show, Conrad Hilton Hotel, Chicago, Illinois.

May 10-11—**American Gas Association** gas supply, transmission and storage conference, Conrad Hilton Hotel, Chicago, Illinois.

May 14-16—**American Petroleum Institute,** Pipe Line conference, Shamrock Hotel, Houston, Texas.

May 22-24—**Pennsylvania Gas Association,** Pocono Manor Inn, Pocono Manor, Pennsylvania.

May 24-25—**Natural Gas and Petroleum Association of Canada,** Shearton Brock Hotel, Niagara Falls, Ontario, Canada.

June 26-29—**Canadian Gas Association,** Manoir Richelieu, Murray Bay, Quebec, Canada.

Sept. 11-13—**Pacific Coast Gas Association,** annual meeting, Coronado, California.

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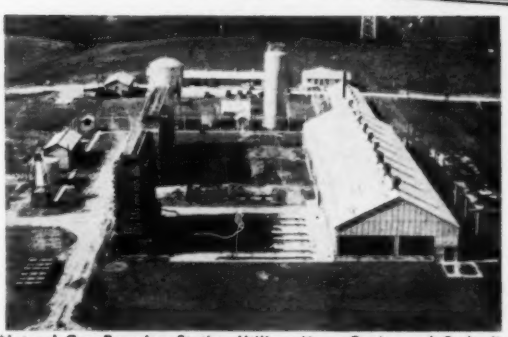

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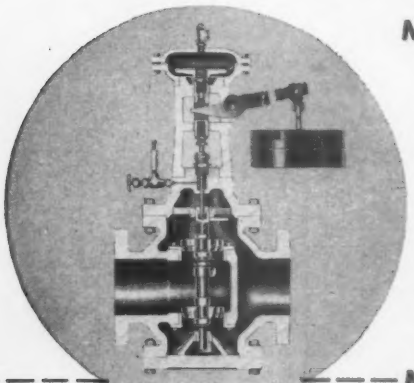

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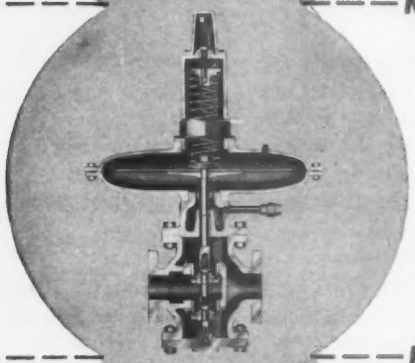
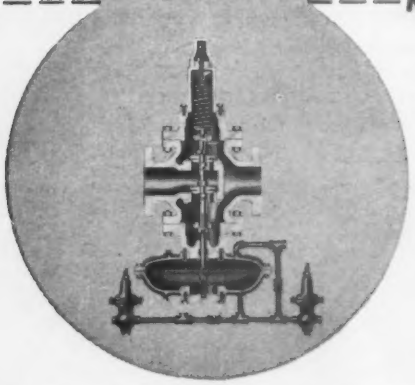


MODEL 44 S
Spring Loaded

A dependable, accurate regulator for distribution service, large industrial or commercial applications, boilers, industrial furnaces, dehydrators, etc. Sizes 2″-6″, flanged F&D 125 lb. body assembly for 100 lb. W. P. Controlled Pressure Range—ounces to 50 lbs. Can be furnished as zero governor. Removable orifices, soft seat balanced valve construction, easily adjustable and removable. Springs colored for identification.



MODEL 44 PC
Pilot Loaded

An accurate efficient pressure loaded regulator for high or low pressure service. Town border settings, compressor fuel lines, transmission measuring stations, large industrial installations. Sizes 2″-12″, flanged for 100 lb., 600 lb., or 1200 lb. W. P. Controlled Pressure Range—ounces to 400 lbs. All flanged construction. MODEL 44 PC—closes on pilot pressure failure. MODEL 44 PO—opens on pilot failure.

OTHER BALANCED VALVE TYPES

Model 44D Duplex Gas Regulators
Model 44B Back Pressure Regulators
Model 44 Diaphragm Motor Valves
Model 46 Industrial Furnace Regulators
SENSITROL Pilot Loading Systems

SINGLE SEAT REGULATORS

Little Hercules High Pressure
H. P. Field Regulator Type 101
House Regulators with Cut-off
H. P. Spring Field Type 149
Dead Weight Pressure Regulators
C-F Type 250 Safety Valves

LONG IN OPERATION • LOW IN MAINTENANCE

ACCURATE *DEPENDABLE*

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